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ADMIRALTY MANUAL OF HYDROGRAPHIC SURVEYING

VOLUME TWO

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CHAPTER I

Marks and Marking

1970

Published by
THE HYDROGRAPHER OF THE NAVY
TAUNTON, SOMERSET

TABLE FOR CONVERTING FEET AND FATHOMS TO METRES

Feet	Fms.	Metres
1		0·305
1·5	¼	0·457
2		0·610
3	½	0·914
4		1·219
4·5	¾	1·372
5		1·524
6	1	1·829
7		2·134
8		2·438
9	1½	2·743
10		3·048
11		3·353
12	2	3·658
13		3·962
14		4·267
15	2½	4·572
16		4·877
17		5·182
18	3	5·486
19		5·791
20		6·096
21	3½	6·401
22		6·706
23		7·010
24	4	7·315
25		7·620
26		7·925
27	4½	8·230
28		8·534
29		8·839
30	5	9·144
31		9·449
32		9·754
33	5½	10·058
34		10·363
35		10·668
36	6	10·973
37		11·278
38		11·582
39	6½	11·887
40		12·192
41		12·497
42	7	12·802
43		13·106
44		13·411
45	7½	13·716
46		14·021
47		14·326
48	8	14·630
49		14·935
50		15·240

Feet	Fms.	Metres
51	8½	15·545
52		15·850
53		16·154
54	9	16·549
55		16·764
56		17·069
57	9½	17·374
58		17·678
59		17·983
60	10	18·288
61		18·593
62		18·898
63	10½	19·202
64		19·507
65		19·812
66	11	20·117
67		20·422
68		20·726
69	11½	21·031
70		21·336
71		21·641
72	12	21·946
73		22·250
74		22·555
75	12½	22·860
76		23·165
77		23·470
78	13	23·774
79		24·079
80		24·384
81	13½	24·689
82		24·994
83		25·298
84	14	25·603
85		25·908
86		26·213
87	14½	26·518
88		26·822
89		27·127
90	15	27·432
91		27·737
92		28·042
93	15½	28·346
94		28·651
95		28·956
96	16	29·261
97		29·566
98		29·870
99	16½	30·175
100		30·480

Feet	Fms.	Metres
102	17	31·090
108	18	32·918
114	19	34·747
120	20	36·576
126	21	38·405
132	22	40·234
138	23	42·062
144	24	43·891
150	25	45·720
156	26	47·549
162	27	49·378
168	28	51·206
174	29	53·035
180	30	54·864
186	31	56·693
192	32	58·522
198	33	60·350
204	34	62·179
210	35	64·008
216	36	65·837
222	37	67·666
228	38	69·494
234	39	71·323
240	40	73·152
246	41	74·981
252	42	76·810
258	43	78·638
264	44	80·467
270	45	82·296
276	46	84·125
282	47	85·954
288	48	87·782
294	49	89·611
300	50	91·440
306	51	93·269
312	52	95·098
318	53	96·926
324	54	98·755
330	55	100·584
336	56	102·413
342	57	104·242
348	58	106·070
354	59	107·899
360	60	109·728
366	61	111·557
372	62	113·386
378	63	115·214
384	64	117·043
390	65	118·872
396	66	120·701
402	67	122·530
408	68	124·358
414	69	126·187
420	70	128·016

Feet	Fms.	Metres
426	71	129·845
432	72	131·674
438	73	133·502
444	74	135·331
450	75	137·160
456	76	138·989
462	77	140·818
468	78	142·646
474	79	144·475
480	80	146·304
486	81	148·133
492	82	149·962
498	83	151·790
504	84	153·619
510	85	155·448
516	86	157·277
522	87	159·106
528	88	160·934
534	89	162·763
540	90	164·592
546	91	166·421
552	92	168·250
558	93	170·078
564	94	171·907
570	95	173·736
576	96	175·565
582	97	177·394
588	98	179·222
594	99	181·051
600	100	182·880

Feet	Metres
700	213·360
800	243·840
900	274·320
1000	304·800

Fms.	Metres
200	365·760
300	548·640
400	731·520
500	914·400
600	1097·280
700	1280·160
800	1463·040
900	1645·920
1000	1828·800

Inches	Ft.	Metres
1	0·083	0·025
2	0·167	0·051
3	0·250	0·076
4	0·333	0·102
5	0·417	0·127
6	0·500	0·152

Inches	Ft.	Metres
7	0·583	0·178
8	0·667	0·203
9	0·750	0·229
10	0·833	0·254
11	0·917	0·279
12	1·000	0·305

Factors

1 Inch = 0·0254 metres
1 Foot = 0·3048 metres
1 Fathom = 1·8288 metres or 6 feet

N.P.134 b (1)

ADMIRALTY MANUAL OF HYDROGRAPHIC SURVEYING

VOLUME TWO

CHAPTER I

Marks and Marking

1970

Published by

THE HYDROGRAPHER OF THE NAVY

To be obtained from

Agents for the Sale of Admiralty Charts

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This Chapter supersedes the whole of Chapter V of the *Admiralty Manual of Hydrographic Surveying* (1948 Edition)

Price 6s. 0d. [30p] net

Printed in England for Her Majesty's Stationery Office
by The Campfield Press, St. Albans

FOREWORD

This Chapter deals with the practical problems of marking the coast and offshore areas for triangulation and control of hydrographic surveys by visual methods.

Metric units have been used in the text as much as possible, but where reference has been made to standard items of equipment which have not yet been allocated metric sizes, British units have been retained.

Similar reasoning has been applied to certain formulae which were originally developed in British units.

The text has been written by a number of officers of the Hydrographic Department and finally edited by Commander J. S. N. Pryor, R.N.

G. S. RITCHIE
Rear-Admiral
Hydrographer of the Navy.

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CHAPTER I

Marks and Marking

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CHAPTER 1 *Marks and Marking*

1. Introduction

The accuracy and speed of progress of both triangulation and sounding depend very largely on the quality of the marks. Good observing targets, properly plumbed, will usually give good triangular closures at the first attempt, while clear, well-sited sounding marks, which can be seen under poor conditions will save much frustration while sounding. In short, time and thought spent over marking a survey area well will seldom be wasted.

2. Siting of Marks

The siting of marks will always be governed by: the configuration and topography of the survey area; considerations of triangulation; and the need to provide well-conditioned fixes. Within these limitations the following factors should be taken into account:

a. Suitability for observing

When appropriate, the site chosen must allow for a theodolite to be set up securely and rigidly, preferably without a false station, and for the surveyor to move round the instrument with reasonable ease without disturbing it. This consideration may tend to disqualify sites such as sloping roof tops, parapets, cliff edges, windward edges of reefs, soft mud, fishing stakes, church spires, high lattice towers, or those that are usable only in very favourable weather.

b. Height

For observing marks, height is almost always an advantage, and hill-tops and cliffs are normally very suitable unless likely to be obscured by cloud. Sounding marks should be placed high enough so that they do not dip below the horizon at the maximum distance at which they need to be seen, but not higher; sextant fixes using elevated marks can contain very significant errors and must be avoided. (See *Admiralty Manual of Hydrographic Surveying*, Volume I, Chapter 4.)

The distance at which an elevated mark can be seen from sea level is given by the approximate formula:

$$\text{Distance in Sea Miles} = 1{\cdot}15 \sqrt{(\text{Height of Mark in feet above sea level})}$$

or the required height of a mark to be visible over a given distance can be expressed approximately as:

$$\text{Height in Feet} = 0{\cdot}76 \,(\text{Distance in Sea Miles})^2$$

c. Visibility

Sounding marks must be placed so that they are clearly visible over the whole area where they are to be used. Marks which disappear for one reason or another are most frustrating when sounding.

Observing marks must see:

(i) Necessary other main stations to give well conditioned figures.

(ii) In all likely directions, to allow for extension of the triangulation.

(iii) As many sounding marks, natural marks, summits, buoys, etc., as possible. Where the triangulation is progressing down a coast, likely positions of future marks and stations must be allowed for.

d. Background

Both sounding and observing marks should if possible be sited so that they will stand out against their background. Plain backgrounds are best, e.g. sky, sea, grass, jungle.

Speckled or intricate backgrounds are bad, and can sometimes render marks invisible from a distance, e.g. towns, tent or caravan camp sites, boulder-strewn hillsides.

e. Ease of Recovery

Marks should be sited so as to be easily recoverable. This implies:

(i) That their position can be quickly found. Marks placed at the corners of fields, on headlands and on summits answer this description; marks placed in the middle of meadows or on long featureless stretches of coast do not, and marks placed half-way up a wooded hillside, if they fall down, may never be found again.

(ii) That they can be properly ground-marked. See Section 3.

(iii) That they can be adequately described. See Section 4.

f. Clearing required

Extensive clearing of jungle and scrub is very time consuming and expensive if local labour is hired. When clearing is necessary, careful selection of the exact site can keep the amount of clearing required to a minimum. Where clearing presents an apparently insuperable problem, as in flat, heavily wooded country, observing towers may need to be built. See Section 9.

g. Permanence

When possible the site for a mark should be selected so that it offers good anchorage points for the guys. It is sometimes possible to reduce the likelihood of the mark being mischievously tampered with by siting it in an inaccessible or guarded spot, such as a police compound, or on private property with the consent of the owner.

h. Accessibility

Easy access for erecting and observing, whether by land, by sea or by air is desirable. However, where this conflicts with other considerations it will carry little weight.

i. Light

Marks placed in open areas are much more easily seen than those placed near trees and buildings where shadows and varying conditions of light may adversely affect their prominence.

j. Size

Marks must be of sufficient size to be seen clearly over the maximum distance required.

A rough estimation of size can be made by calculating the size of shape which will subtend an angle of one minute of arc at the maximum distance. The shape must be more or less equi-dimensional towards the direction it is required to be seen and of uniform colour showing distinctly against the background.

This rule is based upon the assumption that the average unaided human eye cannot resolve objects which subtend an angle of less than 1 to 2 minutes of arc.

3. Ground Marking

All marks should be temporarily ground marked, as soon as they are erected using a bolt stave or other device which cannot easily be moved so that their position can be quickly recovered without any need for re-observing, in the event of the mark falling down or being stolen. Alternatively an accurate description with measurements from permanent objects will suffice.

Permanent ground marks should be established for selected co-ordinated stations and may be made in one of the following ways:

(*a*) A buried concrete post showing about 10 cm above ground. The post should be about 80 cm long and 9 cm in diameter, and should be cemented in at the bottom. Posts should if possible be serially numbered.

(*b*) A triangle or hole cut into an existing rock or concrete surface.

(*c*) A brass triangulation mark stamped with the ship's name and set in cement.

(*d*) Cairns may be built over a ground mark where the materials are readily available on the site. They should be small as a theodolite cannot be placed over a large cairn; also a large cairn takes a considerable time to build.

(*e*) A damaged glass or plastic bottle set in cement may be a better ground mark in areas where bolt staves, non-ferrous metals and other useful articles are attractive items.

(*f*) Buried marks similar to those mentioned above, or consisting of a concrete block, may be used for greater permanence, but an accurate description with measurements from several permanent objects in the close vicinity is essential.

Unless motor transport can reach the station permanent marks involving substantial quantities of concrete should not be attempted. Concrete and cement used for marking stations should be mixed not weaker than one part of cement to three parts of gravel or sand. Where a station is liable to be awash at high water rapid hardening cement should be used. Fresh water and sand free of salt should always be used if conditions permit.

4. Descriptions

Marks which are to be co-ordinated should be described as soon as they have been ground marked. A good description should enable the position of the mark to be recovered to within a few centimetres. Any of the following may contribute to a description:

(*a*) Witness marks established close by, with measurements. These may take the form of crosses cut on rock, or identifiable trees.

(*b*) Measurements to easily recognised points, situated preferably within 50 metres. If roads, hedges, walls, etc., are used, the measurements are best made to their centre-lines.

(*c*) Measurements along fences, etc. to where they are intersected by lines of sight from the mark to distant conspicuous objects.

(*d*) Measurements of offsets from the mark to natural transit lines.

(*e*) Magnetic bearings to easily recognised objects close by (i.e. within about 100 metres). Bearings may also be given to distant objects if there is any possibility of incorrect identification.

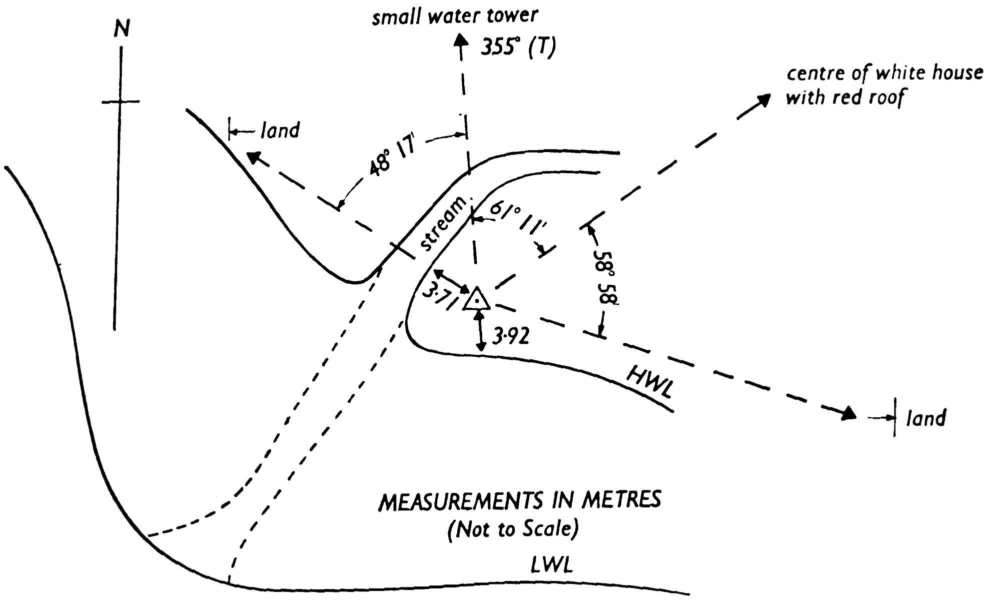
(*f*) Sextant angles to suitable permanent natural marks.

(*g*) Photographs of the station and its surroundings.

(*h*) Photographs or sketches of transits, etc., as seen from the station.

(*i*) Any writing or inscription on the mark itself.

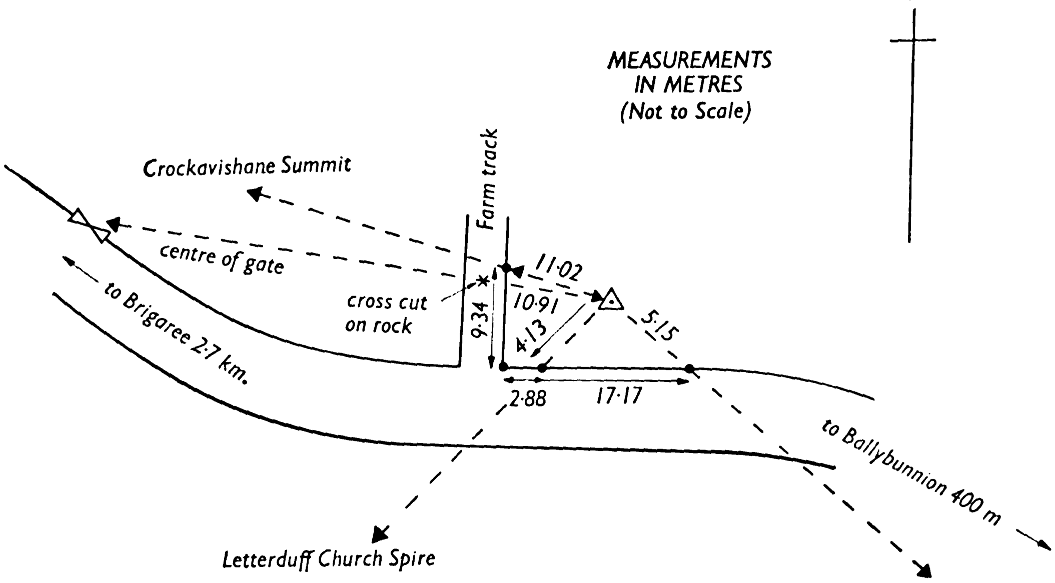
Three examples of descriptions are shown.



Description of Triangulation Station

Fig. 1-1a

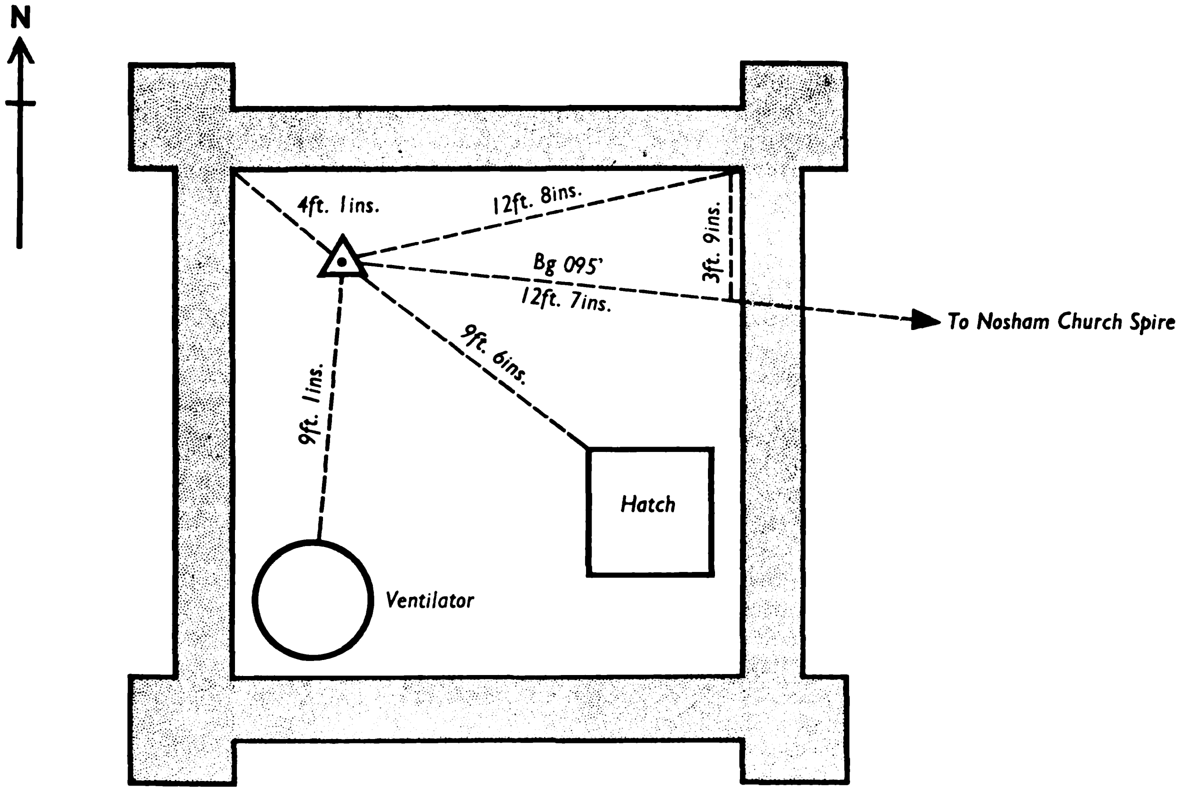
The station (Fig. 1–1(a)) is marked by a concrete post 9 cms in diameter buried with about 5 cms showing above ground, and marked: $\overset{\text{H.D.}}{\underset{127}{\circ}}$ on the top. It is situated on a sandy point about nine cables ESE of Tanjong Gelu.



Description of Triangulation Station

Fig. 1-1b

The station (Fig. 1–1(b)) is marked by a brass triangulation plate inscribed 'HMS HECATE 1970' set in a cement block 30 cms square and 6 cms thick and buried 40 cms deep in the SW corner of Mr. O'Brien's field, about 400 metres west of the centre of Ballybunion Village.



Description of Triangulation Station
Fig. 1-1c

The station (Fig. 1–1(c)) is marked by a small triangle △ cut in the lead roof on the top of Belham Church Tower. Measurements are given in the diagram.

5. Plumbing of Observing Marks

When theodolite observations are to be made to a mark, the actual sighting point must be obvious, unambiguous, and clearly understood by all observers. This sighting point, with a pole mark, will normally be the centre of the pole at the bottom corner of the flag, this being also the point where the pole is guyed. With other marks it may be the cross or apex (as with a tripod or triangular shape) or the centre (as with oil drum marks, etc.).

This sighting point must be most carefully plumbed over the ground mark; a divergence of more than a centimetre out of plumb should be considered unacceptable for a main triangulation station, and for close range observing, with rays of a kilometre or less in length, even greater accuracy should be aimed at if the triangulation is to be marked permanently and likely to be extended.

In calm weather, and where the sighting point is not more than two or three metres above ground level, a plumb line may be used with success; with higher marks, or on a windy day, the sighting point must be plumbed by theodolite. To do this, set up and level the instrument at a convenient point in line with one pair of guys (or legs) and about twenty or thirty metres distant. Intersect the ground mark, clamp both horizontal plates, elevate the telescope to the height of the sighting point, and adjust the guys (or legs) until the sighting point is intersected. Repeat the operation with the instrument in line with the other set of guys, and continue until no further adjustment is necessary. With two theodolites the process is a good deal quicker.

When the station is being first established, it may be simpler to erect the mark and then site the ground mark beneath it by plumb line or theodolite. For close range work the use of small targets mounted on spare instrument legs plumbed over the stations being observed is a convenient way of ensuring precision while observing if the terrain allows the use of such low marks.

6. Night Observing Marks

Both directional and non-directional lights are suitable for night observations. Directional lights need lining up and tending, require a carefully planned observing programme if several stations are to be occupied, increase the observing time needed, and are more reliant upon adequate communications. Non-directional lights do not have as great a range, need more careful shading from the observer, and are less suitable for signalling.

Paraffin pressure lamps, hung either under or over the theodolite (preferably the latter) and suitably shaded, have been used with success for rays up to 45 kilometres in length, and are quite well suited to the type of observing likely to be undertaken by the hydrographic surveyor. Coloured shades may be used if there is a possibility of the white light being confused with other lights; alternatively, if the reduction in range due to the shades is unacceptable, two or three pressure lamps may be hung in a vertical line.

For ranges in excess of about 40 kilometres a direction signalling lamp will be the most suitable. For short rays of under about 6 kms the paraffin pressure lamp should be masked, or a less powerful light used. A single torch bulb without reflector will be found bright enough for rays up to about 3 kms long.

When observations for true bearing are being made on stars at night, a suitable reference object (RO) is required. The observations are usually made from a suitable, conveniently-sited main station while another main station can be used as the RO, a torch being used as the luminous mark. If it is inconvenient to occupy a distant station, it is sufficient to set up a closer temporary reference object, provided it offers a precise target. The distance to this temporary RO should, if possible, not be less than 2 km. The grid bearing to it should be ascertained in daylight by observations at the main station. For the night observations, a small torch or hurricane lamp should be sited in position at the reference object. Even these may prove to be too powerful for such a short range in which case the light should be masked.

7. Day Observing Marks

Day observing marks can be luminous (the heliostat, which will be discussed in Section **8**) or opaque.

The ideal characteristics of a mark for observing and for sounding are somewhat different, and if a mark is to be used for both purposes a compromise is necessary. For observing, a mark should be no larger than necessary, of regular shape when viewed from any direction; should have a clear-cut sighting point so that short rays can be observed as accurately as long ones, should be easy to plumb and should, if possible, be able to be left in place when the station is occupied by an observer. It should also be immune from the effects of phase (i.e. one face of a square or cylindrical mark is in sunlight and is visible, while the other is in shadow and difficult to see). Few marks will meet all these requirements.

Types of marks commonly used are:

For very long ranges (over 30 kms)	Heliograph
For long ranges (over 15 kms)	Tall pole marks Oil drum pyramids Large quadripods
For medium ranges (10–15 kms)	Large shapes Pole marks
For short ranges (under 10 kms)	Small shapes Plywood targets
For very short ranges (under 2 kms)	Rocket stick Nail Small target on instrument legs

8. The Heliograph

Before carrying out observations with heliographs, a written programme, giving periods and times for operating the signals towards each observer, should be supplied to each observer and operator. Radio communications between observers and operators are a great assistance but, if not available, a simple, single-letter code should be devised and routine messages transmitted by morse letters flashed on the heliograph. This latter method is only really practicable under cloudless conditions.

For observing very long rays or in hazy visibility when there is sunshine, a heliograph is the ideal instrument for the job. Its advantages and disadvantages can be listed as follows:

Advantages

(1) It is compact and easy to carry.

(2) It is relatively cheap and has no running costs.

(3) It has a very long visibility range in good conditions. Ranges up to 70 miles have been obtained with heliostats.

(4) It can be easily, quickly and accurately set up over a station.

(5) Its visibility is unaffected by the background.

(6) It is not subject to any phase effect.

Disadvantages

(1) It can only be used with sunshine.

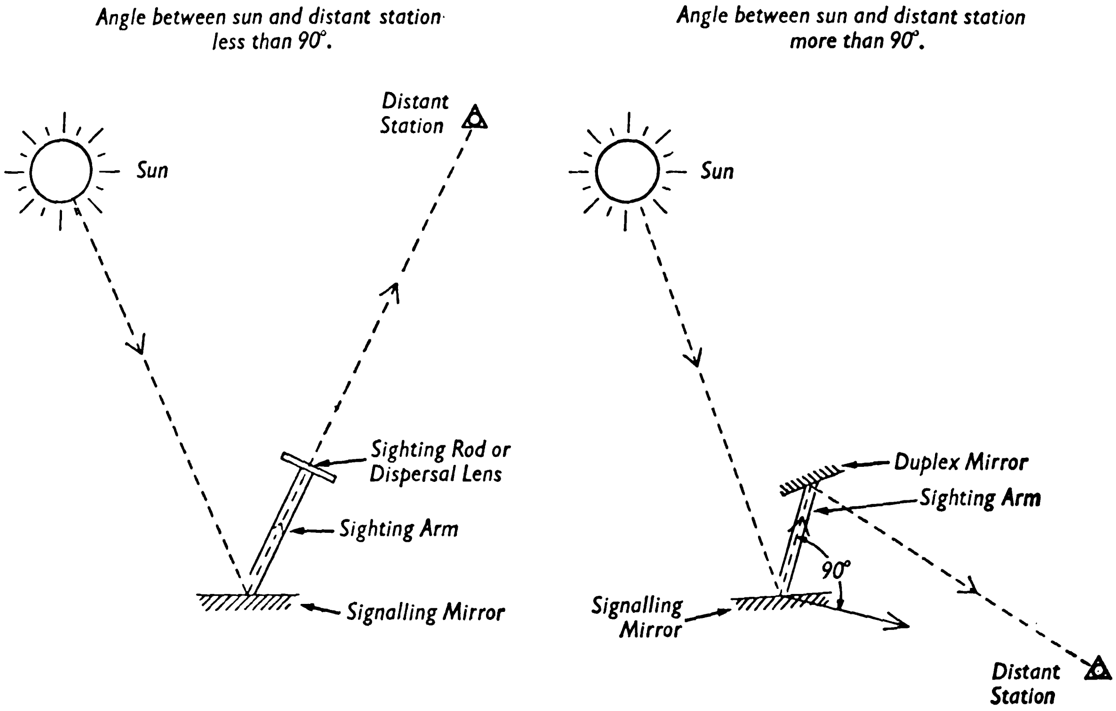
(2) It requires constant attention due to the movement of the sun.

(3) It can only be used by one observer at a time.

(4) It has a very narrow beam, and therefore requires accurate pointing. A heliograph projects a beam diverging at about 32 minutes of arc (the angle subtended by the sun at the earth's surface) which is about 50 feet wide at a mile distance. Reduced light or 'penumbral effect' is received at the edges of this beam, so for maximum effect it is important that the centre of the beam is accurately directed.

The heliograph supplied to surveying ships of the Royal Navy is the Army 5 inch Mark V Heliograph. The instrument is supplied with tripod legs and is carried in two leather cases, the larger one containing the heliograph and Duplex mirror and the smaller one the dispersal lens and attachments. It is primarily intended for signalling purposes and is therefore fitted with a spring-loaded keying device at the rear of the signalling mirror so that morse letters can be easily flashed. For surveying purposes the sun can be continually reflected by clamping this device.

With the aid of a Duplex mirror, sunlight can be reflected over a full 360° arc irrespective of the position of the sun, as shown by Fig. 1–2. With some loss of brilliance and hence


Angle between sun and distant station less than 90°.
Sun
Distant Station
Sighting Rod or Dispersal Lens
Sighting Arm
Signalling Mirror
Angle between sun and distant station more than 90°.
Sun
Duplex Mirror
Sighting Arm
90°
Signalling Mirror
Distant Station

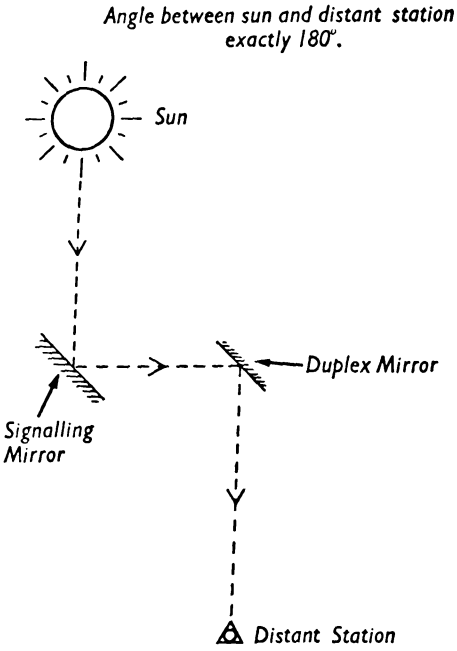


Fig. I-2

HELIOGRAPH-METHODS OF REFLECTING THE SUN'S RAYS.

range, a dispersal attachment may be fitted to increase the divergence of the reflected ray from 32 minutes of arc to about 5°; the cross section of the ray is then in the form of an ellipse with its major axis horizontal. When the angle at the heliograph between the sun and the distant station is less than 90°, the signalling mirror is simply used with the sighting rod. When the angle is more than 90°, the Duplex mirror is used in place of the sighting rod. Various views of the instrument, fitted with straight and jointed sighting rods and the Duplex mirror, are shown in Fig. 1–3.

a. Setting up the instrument to reflect the sun through angles less than 90°

The tripod legs are first roughly set up over the station. Next the signalling mirror is inserted into the socket which forms one end of the sighting arm and then screwed into the head of the tripod. The threaded portion of the vertical rod behind the mirror is then centred in the nickel silver ball C at the top of the mirror. The procedure is then as follows:

(i) Insert the straight or jointed sighting rod, as desired, into the small socket of the sight arm. With the jointed rod, the outer end should be vertical and the rod should be in prolongation of the sighting arm. The movable vane on the sighting rod should be turned down to the horizontal.

(ii) Unclamp the screw A on the vertical column behind the signalling mirror, elevate the mirror about half-way and reclamp.

(iii) Lift the tripod legs and turn it so that the sun's rays are thrown in the direction of the distant station. Plumb the heliograph precisely over the station and press the legs well home in the ground, keeping the head of the tripod as level as possible.

(iv) Unclamp the large end of the sighting arm with screw B and turn it until the nickel silver ball C and the top of the cross wires on the top of the sighting rod are in line with the distant station. Reclamp the sighting arm with B.

(v) Adjust the mirror until the reflected rays are directed approximmately at the distant station.

(vi) Move in front of the heliograph and with the back to the sun, look into the signalling mirror. Move the head until the reflected image of the distant station is hidden by the unsilvered spot D in the centre of the mirror. Keeping the head still, move the sighting rod until the reflected images of the distant station and the centre of the cross wires on the sighting rod coincide with the unsilvered spot D.

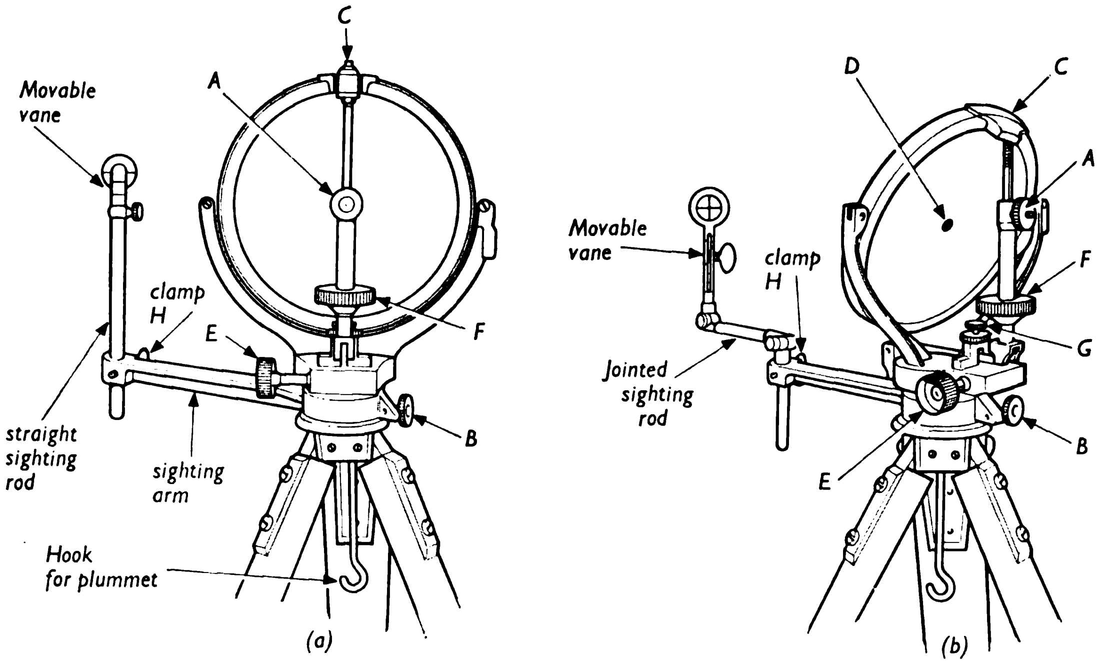
(vii) Turn up the movable sight vane on the sighting rod, taking care not to disturb the alignment, and using the tangent screw E and collar F, adjust the shadow spot until it covers the sighting spot on the movable vane. If the heliograph is going to be used for signalling, make sure that the screw G is fully screwed *down* and clamped with the lower locking screw. The instrument is then correctly aligned on the distant station. If it is desired to use the instrument for signalling, the beat regulating screw G should then be slackened until the shadow spot rests on the next line below the sighting mark on the sight vane and then locked. Morse signals can then be made using the collar F as a key.

b. Setting up the instrument to reflect the sun through angles greater than 90°

The instrument is first set up as above and the procedure is then as follows:

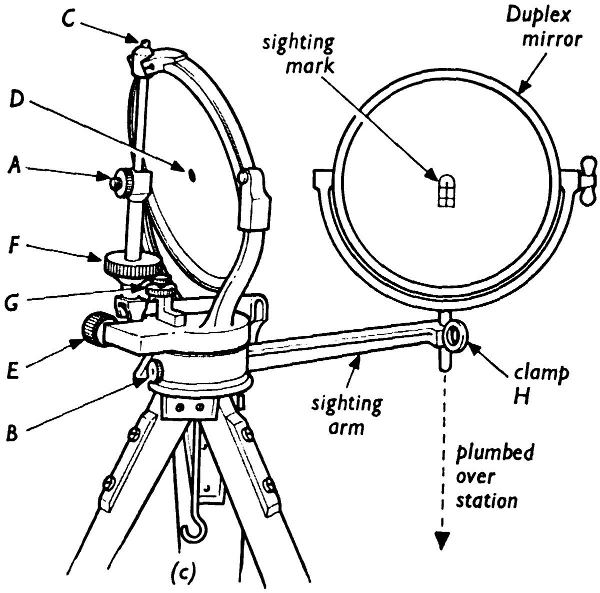
(1) Insert the Duplex mirror in the end of the sighting arm instead of the sighting rod as shown in Fig. 1–3(c), such that it faces the signalling mirror and is parallel to it. It should be clamped in place with clamp screw H so that the mirror bracket

THE 5" MARK V ARMY HELIOGRAPH.



(a) Rear view of signalling mirror with straight sighting rod fitted.

(b) Three-quarter view of signalling mirror partially elevated and jointed sighting rod fitted.



View of Heliograph with Duplex mirror fitted.

A Clamping screw for vertical rod
B Clamping screw for signalling mirror end of sighting arm
C Nickel silver ball
D Unsilvered spot in centre of signalling mirror
E Tangent screw for signalling mirror
F Collar and signal key
G Beat regulating screw
H Screw clamp at small end of sighting arm

Fig. 1-3

is about a quarter of an inch above the sighting arm and the mirror can be turned stiffly.

(2) Elevate the signalling mirror slightly and reclamp.

(3) Lift the tripod and turn it so that the sight arm is at an angle of 90° to the distant station on the side on which the angle between the sun and the distant station is less than 180°. Plumb the *Duplex mirror* over the station and press legs home.

(4) Stand facing the signalling mirror and, keeping the head still, adjust the Duplex mirror and the sighting arm so that the reflection of the distant station, as seen in the signalling mirror, is exactly covered by the sighting mark on the Duplex mirror. Continue this adjustment until both the above marks are aligned with the unsilvered spot on the signalling mirror.

(5) Adjust the signalling mirror as in 8a (vii) above, so that the shadow covers the centre of the sighting spot on the Duplex mirror.

The instrument is now aligned on the distant station and can be used for signalling if desired.

In setting up the heliograph, it is recommended that the reflection of the shadow spot should first be found on the hand and then by manipulating the collar and tangent screws bring it on to the vane. To keep the correct alignment as the sun moves, the collar and tangent screws must be adjusted to keep the shadow spot on the sighting vane. When the sun is very low and the Duplex mirror is being used, it may be necessary to depress the sight arm by moving the tripod legs, to ensure that the sun's rays fall fully on the signalling mirror.

At very short distances, the reflected light will probably be too strong. The strength can be reduced by aligning the heliograph slightly below the distant station so that the 'penumbral effect' mentioned above, is being used. If used for signalling under these conditions, the key beat regulating screw G should be slackened so that the shadow spot rests about half an inch below the sighting mark on the sight vane. Alternatively the dispersal attachment can be fitted or the light can be reduced by 'stopping' the signalling mirror down with a card with a circle cut out to reduce the reflecting area. A rough guide is that one inch of diameter of the mirror surface should be allowed for each 10 miles of the length of the ray being observed.

c. Setting up the instrument with the dispersal attachment

The dispersal attachment can be used to reduce the intensity of light or to increase the width of the beam if the distant station's position cannot be seen and is only approximately known. It can only be used when reflecting the sun through an angle less than 90°. It is carried in the smaller leather case and consists of the dispersal lens with a sighting mark in the middle, a special sighting arm and tripod head adaptor. To ship the attachment, the adaptor is first screwed into the base of the signalling mirror and the whole fitted into the socket at the wide end of the sighting arm. The complete unit is then screwed into the tripod head. The sighting arm should have its flat side uppermost.

The dispersal lens is then fitted by passing the stem down through the square hole on the small end of the sighting arm and engaging the threaded portion by screwing up on the milled knob underneath. The heliograph is then lined up on the distant station in the same way as with a sighting rod described in a. above. In lining up the nickel silver ball C and the dispersal lens with the distant station as described in stage 4, it is best to line the top of the dispersal lens rather than the sighting mark in the centre.

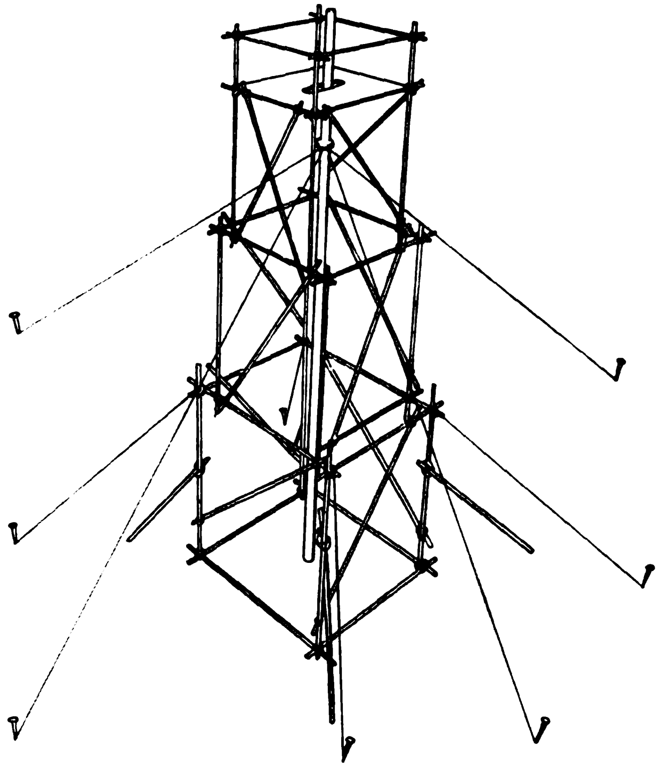
9. Observing Towers

These are essential when the observations at a station have to be made at a considerable height above the level of the ground in order to observe a long ray from a low-lying station or over the tops of trees that cannot be cleared. There is generally a certain amount of vibration in the tower and observations are not quite as satisfactory as observations obtained in the normal manner from the theodolite tripod. More rounds should be taken in order to obtain the accepted observed angle.

The tower should consist of two independent but concentric structures, the inner one supporting the theodolite and the outer one carrying a platform to support the observer. It is important that the two structures do not touch in any way so that vibrations from the observer's platform are not transmitted to the theodolite. For a low tower, about 3 to 5 metres high, the inner tower can be satisfactorily constructed as a tripod from three hop poles or dan buoy staves, with their ends lashed to the theodolite legs, unguyed, and the outer tower from tubular scaffolding or bamboos, guyed.

Fig. 1-4

An observing tower



Figs. 1-4 shows a successful tower, nearly 12 metres high, made with a firmly guyed barling as the central structure. The outer tower was made with tubular scaffolding and planks for the observer's platform. The theodolite legs can be lashed to the top of the barling, but in the case illustrated, a special clamp was constructed.

When observing into an observing tower, it will be necessary either to mark the inner tower or to use a heliograph. The observing tower itself should not be taken as the mark, because it is most unlikely to present a symmetrical appearance.

10. Natural Marks

Natural marks and existing man-made structures such as lighthouses, spires, etc., are of limited use as triangulation stations, because when observing at them it is usually necessary to have a large false station. When they are suitable (lattice towers, some church towers and water towers, etc.) they offer the advantages of being permanent and easily identifiable.

If of a permanent or semi-permanent nature, they should in any case be co-ordinated and described. It is important to remember that structures such as radio towers, flag staffs, etc., are liable to be taken down and rebuilt from time to time in a slightly different position. The description must be written in such a way that it will be obvious if this has occurred.

The fullest use should be made of natural objects as sounding marks, as these are frequently the most easily seen. The type of object which is suitable will depend on the scale of the survey: on a scale of 1: 50,000 the centre of a clump of trees or large house could be used without any likelihood of error, whereas on 1: 10,000 a single tree or a particular gable of a roof would have to be selected.

11. Pole Marks

These are the most commonly used marks in a hydrographic survey. They consist of:

a. A pole

Those commonly used are boat-hook staves, which are light and straight; hop poles, which are heavier, longer, and quite straight; bamboos (male), which are longer and as light as hop poles, but not quite as strong or as straight, and which are often combined with a boat-hook stave for a total length of about 12 metres; and barlings, 12 metres long, straight, strong and very heavy, used only occasionally for very tall marks or for tripods in the water.

b. A flag

These are supplied in two sizes: 16 ft. × 10 ft. and 8 ft. × 4 ft. 6ins., and in various colours. Striped and multicolour flags are not easy to see particularly against a mixed background, where they can easily blend in and disappear. Large flags (half red and half white) are usually the best against a land background, plain black against sea or sky. If marks are to be used (other than only for observing) at ranges greater than three miles, large flags should be used. Fluorescent flags are also available; these show particularly well in sunlight and when new, but the material they are made from fades and rots comparatively quickly. For obvious reasons adjacent marks should not be identical, particularly where they are close together. If conditions dictate that the main flags of neighbouring marks have the same colours then additional bunting or shapes should be added to give a clear distinction between them. The flag should be lashed to the pole with spunyarn, top and bottom lashings being put on first to keep the flag taut. The visibility of a flag, whatever its colour, position or background, will depend mainly on the wind strength and direction. The darkest colour of parti-coloured flags should be placed uppermost to give the maximum contrast against a part sky background.

c. The guys

These are best made from seizing wire: 3½ or 4 mm in diameter wire is most suitable for very large marks; 2½ mm for medium sized and small marks. The mark should have four guys meeting as nearly as possible at right angles. A pair of guys is best made from one length of wire, being secured to the pole with a clove-hitch just above the lower flag lashing. The guys should be rigged so that they make an angle of about 40° with the ground, and must be set up taut.

d. The stakes

These may be made from round, square, angle or **T** section mild steel bar and should be from ½ metre to 1 metre in length and 20 to 50 mm cross section depending on the holding power of the ground. They should when possible be driven well in at a good angle so that the pull of the guy tends to drive them deeper. In soft ground or shallow turf they may need to be doubled up or otherwise strengthened; some possible methods are discussed in the *Admiralty Manual of Seamanship*, Volume II.

e. 'Buffing'

When marks need to be seen at more than about 5 kms, some form of 'buffing' is usually added, so that their visibility does not depend solely on the flag. This may consist of:

(i) A shape: *see* Section **14**.

(ii) Paint: a white-painted pole will often stand out quite well against a background of trees even when the flag is hanging limp.

(iii) Bunting: the most common form of buffing. The most effective way to use it is to hang strips down the guys. The strips will need to be some 6 metres long and about 40 cms wide (twice this width for very long range marks). The strips should start where the guys meet the pole, and should be attached to the guys every metre or so by threading the edge of the material between the strands of the wire. When the guys are up the bunting should be stretched taut along them, without actually taking any weight. Either two opposite guys or all four should be so treated. The end result should be of strips of bunting hung down the guys like long sheets on a clothes-line, and forming a clear inverted—**V** when seen from any direction. Some positions for a mark draw the eye naturally towards them, for example, summits, small isolated buildings, cliff-tops, jetty heads, etc. Marks so situated will be much more easily seen. *See also* Section **2** (Siting of Marks).

f. Heel guys

When the heel of the mark is likely to shift it should be secured with wire guys to all four stakes. The need for these guys can be avoided if the heel of the pole can be held firmly in some other way, e.g. digging-in or lashing to a stake.

12. Masts and Tall Marks

a. Lambda masts

The details of rigging and erecting a Lambda mast are to be found in Decca publications. The following brief description will suffice to explain the principles involved.

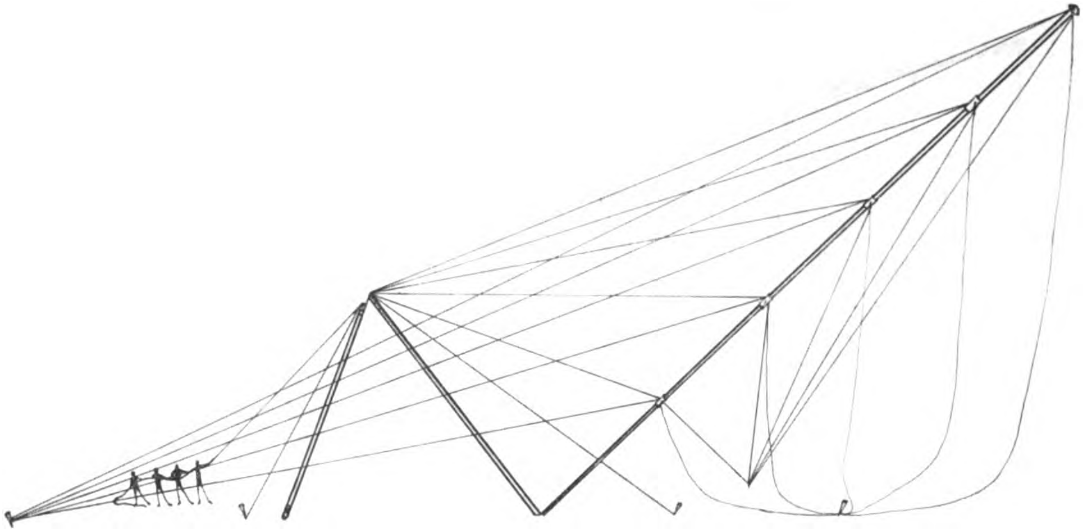
(i) Site the mast base at the centre of a suitably flat and level area (if possible) and peg or cement it in.

(ii) Lay out the stakes 90° apart, and 15 metres from the mast base with a theodolite and tape. If the ground slopes, this distance should be increased for the downhill stake to preserve the angle of the guys with the masthead. If the slope is considerable the downhill guys may need lengthening and possibly the uphill ones shortening.

(iii) Rig and lay out the mast (30 metres long). It should be hoisted across the slope and into or nearly into the wind. If these requirements conflict, the surveyor must use his judgement. If the ground slopes, the mast should be laid out uphill of the back stake by an amount equal to the slope; i.e. looking from the mast base, if the ground slopes 10° down to the left, the mast when laid out for hoisting should pass 10° to the right of the back stake. If the ground is uneven, trestles may be needed to keep the mast straight.

(iv) Rig the hoisting boom (9¾ metres long) to make an angle of 87° with the mast.

(v) Rig the hoisting guys taut to the end of the boom, the side guys taut to their stakes, the back guys slack to the back stakes and clear of the mast. All shackles and bottlescrews to be well greased.



Lambda Mast being erected.
Fig. 1-5

(vi) Drive in the hoisting stake at 10 metres from the base in the direction of the front stake. Rig the Tirfor winch or hoisting tackle from the hoisting stake to the end of the boom.

(vii) Drive in the boom guy stakes at 10 metres from the base in the direction of the side guys.

(viii) Erect the boom and guy it to its guy stakes with two-inch cordage or similar.

(ix) Haul on the hoisting tackle, or Tirfor until the mast is clear of the ground along its whole length. Check that all rigging is tight and moused. Adjust the guys if necessary so that the mast hangs straight, making the correct angle with the boom.

(x) Hoist steadily, tending the side guys.

(xi) When nearly vertical, take down the slack on the back guys and tend them.

(xii) When vertical, transfer the hoisting guys to the front stake, carefully, one at a time.

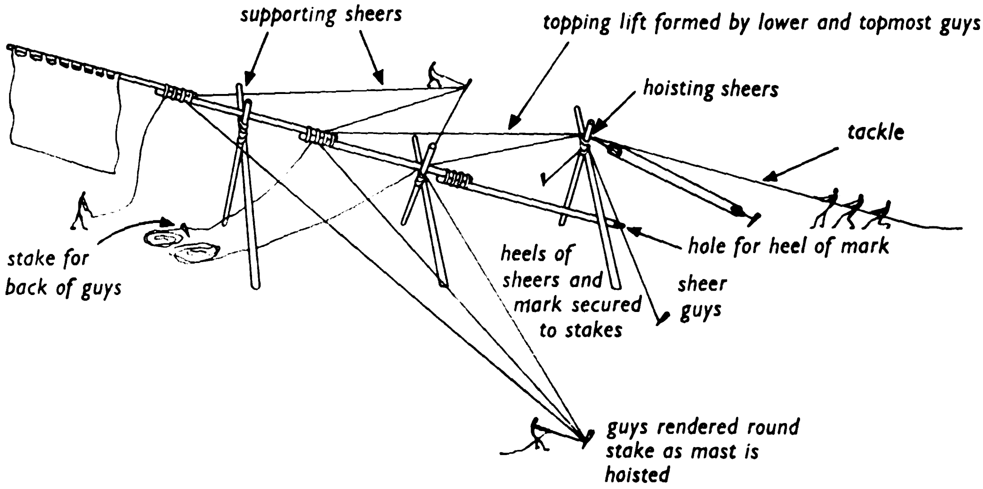
(xiii) Check the mast for straightness and uprightness using a theodolite.

b. Tall marks

Marks more than 12 metres high may sometimes be required to enable long rays to be observed by theodolite.

A suitable combination of spars should be lashed together to give the required height, overlapping by about 2½ metres at each join, and guyed at each overlap. The bottom of the flag must also be guyed in the usual way.

One possible combination of spars might be: barling, two bamboos bound together head to tail, a hop pole, and a boat-hook stave or a second hop pole. This would give a mark about 20 metres in height which can be raised in a similar manner to that already described for a Lambda mast. A barling should be used as the boom.


supporting sheers
topping lift formed by lower and topmost guys
hoisting sheers
tackle
hole for heel of mark
stake for back of guys
heels of sheers and mark secured to stakes
sheer guys
guys rendered round stake as mast is hoisted

Raising a tall mark with a topping lift
Fig. 1-6

Most careful attention will need to be paid to the firmness and holding power of the stakes.

The flag is best rigged by stopping it to the pole with small thread. A smiting line, or burster, is rove through the stops so that the flag can be broken out when the mark is finally erected and secure.

Rigging the flag in this way reduces windage and keeps it from getting foul during the hoisting operation.

13. Quadripods and Tripods

Quadripod and tripod marks are similar in construction. The tripod is probably a little easier to erect and requires less material, but is less robust and less symmetrical to observe to. Permanent beacons for land survey main triangulation stations are usually quadripods.

Pole marks are simple to erect and require the minimum of material and labour, but their main disadvantage is that observing at them requires a false station to be made or the pole to be moved from over the ground mark.

Tripods and quadripods are therefore often used so that the true station can be occupied and at the same time allow observations to be made to the station. They are also more substantial and therefore more easily visible than a pole mark.

Positioning a tripod or quadripod accurately over an existing station can take a considerable time. When establishing a station for the first time it is advisable to erect the mark first and plumb the ground mark in directly below the apex.

They can be made very conspicuous by the addition of slats or bunting secured across the legs together with a pole and flag top mark.

a. Erecting a quadripod mark

A quadripod like the one illustrated in Fig. 1–7 can be constructed with four suitable hop poles, bamboos or small tree trunks about 8 metres in length. They are first laid on the ground, with the butts all level, in two pairs on top of one another. The tops of the spars are lashed firmly together with rope and then raised to the vertical position. If particularly heavy, they can be raised by a boom as described in Section 12 for raising a tall pole mark. When vertical, the legs of the quadripod are splayed out, causing the head lashing to bind tightly.

The heels of the spars should be buried or securely lashed to stakes driven into the

A quadripod survey mark

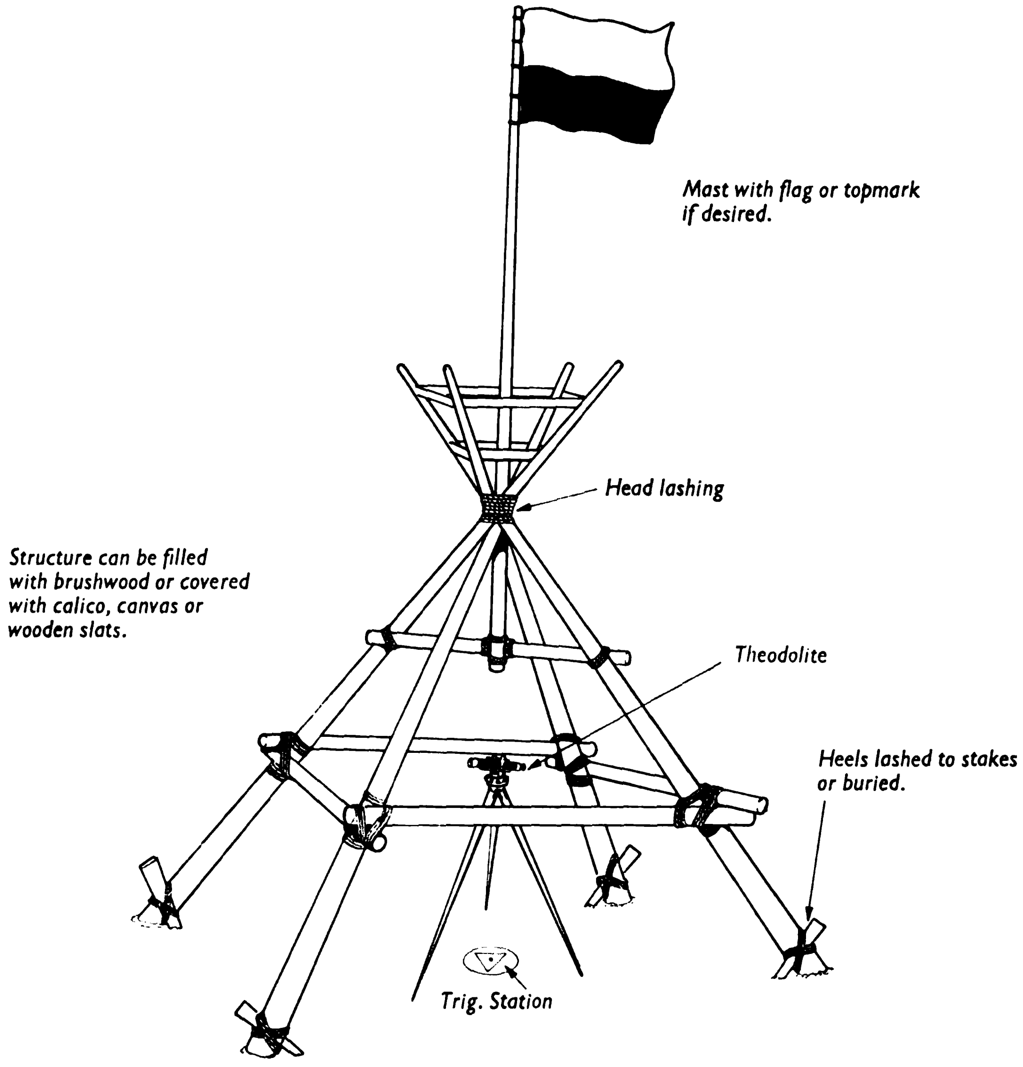
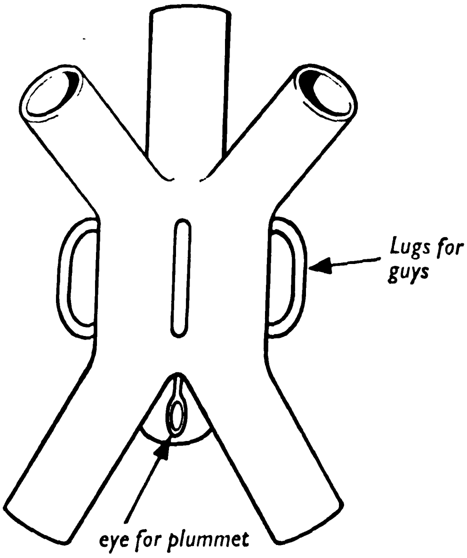

Mast with flag or topmark if desired.
Head lashing
Structure can be filled with brushwood or covered with calico, canvas or wooden slats.
Theodolite
Heels lashed to stakes or buried.
Trig. Station

Fig. 1-7

ground. For a mark erected on solid rock or a coral reef, it may be preferable to secure the heels to sinkers. Additionally guys from the head lashing may be rigged for marks in exposed positions or on sites covered by the tide.

Spars or baulks of timber lashed or nailed between the main spars will give added strength to the structure and help support any filling material used to make the mark more conspicuous. If it is desired to make the mark dark against a light background such as the sky, it can be fitted with a 'floor' of saplings and branches nailed across at a level six or more feet above ground level, and the whole structure filled with brushwood.



Tripodial coupler

Fig. I-8

b. Tripod marks

A tripod mark can be erected in exactly the same way as a quadripod except that three spars are used.

If a tripodial coupler, illustrated in Fig. 1–8, is available, a very robust tripod structure can be erected with tubular scaffolding. The coupler is made with specially bent piping welded together. The angles between the short legs of the coupler are fixed at 60° and three lugs are fitted for the attachment of guys. A small eye is provided at the bottom end for suspension of a plumbob. Overall height of the coupler is 18 cms and it weighs about 4 lb (2 kilos).

14. Shapes

Wooden shapes as shown in Fig. 1–9 can be easily made. They are particularly useful for triangulation in a river, or as close range sounding marks when trees or mangroves come down to the water's edge. They will stow flat, are quickly assembled, and can be readily hung from branches of trees.

Canvas and fluorescent triangular shapes are supplied for buffing up pole marks, or as observing targets. They need strong support, as they tend to catch the wind. Several can be laced together if an extra large target is required. The canvas ones require painting or whitewashing before use.

Whenever possible shapes should be positioned so that the visible face is sloped to reflect light from the sun or sky.

Crumpled metal foil covering a ball or other solid shape is also effective for reflecting sunlight where foliage may cast shadows on other types of surfaces.

15. Whitewash Marks

Whitewash is invaluable to the surveyor. It is cheap, easily obtainable and only requires to be mixed with water, salt or fresh, to be ready for use. As the dry mixture deteriorates in a humid climate, it should be stowed in sealed metal containers.

Whitewash can be used on cairns, tree trunks, buildings, canvas, shapes, dark rocks or

SURVEYING SHAPES

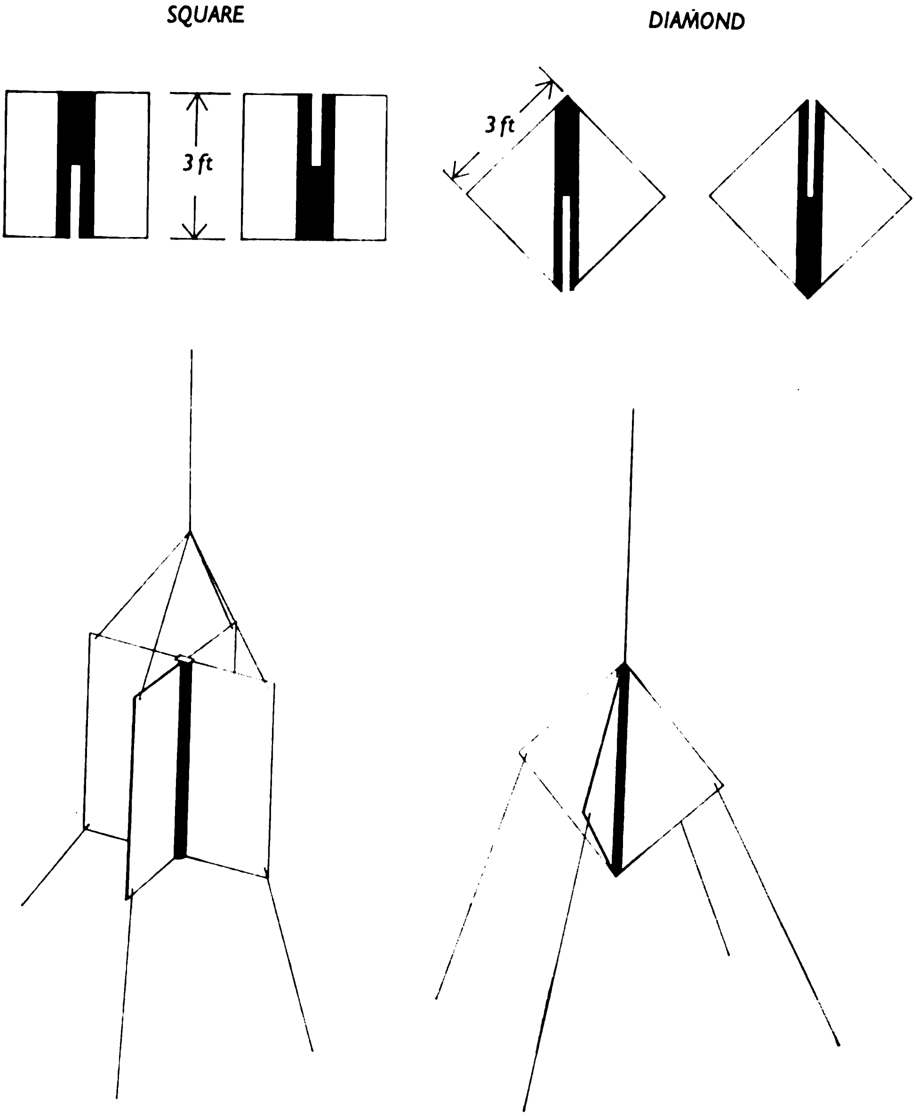


Fig. 1-9

cliff faces. It should not, of course, be used where it can be confused with guano deposits or snow.

To mix whitewash, a bucket should be used and quarter-filled with the dry, pulverised mixture. About a gallon of water is then added and the whole stirred thoroughly. A bucket of whitewash is more than sufficient for a very large mark. A large distemper brush is usually used to apply the whitewash. The immediate result is usually disappointing but the final result is invariably white and conspicuous after it has dried, provided it has been applied on a dark object with a dark background. A second coat may be necessary for the best results. A large, clearly defined shape is more readily identified than an irregular splodge.

A blob of red paint in the centre of a whitewash mark will help to make it visible under all conditions of light.

Once dry, whitewash will not easily wash off and may still be visible under normal circumstances a year later.

16. Marks in Shallow Water

It often happens that marks need to be erected in positions sometimes or always covered by water. In deep water a floating mark can be laid (*see* Sections **17** and **18**); in shallow water (up to about 5 metres deep) one of the following methods may be used:

a. Erecting a tripod from a boat

A tripod can be formed of three hop poles or barlings. The former can be laid in depths up to 2½ metres and the latter in depths up to about 5 metres at low water if the tidal range does not exceed about 3 metres.

To erect a barling tripod, a large motor boat or whaler should be used and the procedure is as follows:

Select an even portion of the bottom with suitable depths; anchor the boat in position by the stern about an hour before low water. The tripod is rigged in the boat as shown in Fig. 1–10. Sinkers of about 100 kilos are attached as heel weights.* The legs are stopped on each quarter and in the bow. A stop will also be required round the head lashing to hold the cross of the tripod down in the boat. It is important that the head lashing is not too tight otherwise the legs will not splay properly. A preventer should be rigged between the two legs projecting over the stern to prevent these legs splaying too far in the initial stages of laying.

Ease the two after legs down to the bottom by loosening the lashings and bearing up on the head lashing in the centre of the boat at the same time hauling astern on the anchor. It is sometimes convenient to anchor the boat head and stern in the direction of the stream. This gives more control over the movement of the boat.

When the third leg is making the correct angle with the after pair it should be lowered to the bottom. At this stage some lateral movement of the third leg may be required in order to get the structure symmetrical and stable; a motor boat in attendance is useful to pull the working boat to one side or other of the line of its anchors before the heel of the third leg is finally placed on the bottom.

A swifter of wire or cordage should then be passed round all three legs as low down as possible to prevent splaying. Shallow water divers are useful for this operation.

In exposed positions or where the streams are strong it is advisable to lay out four guys from the head of the tripod to anchors and sinkers.

A bamboo pole and flag topmark may be rigged when the tripod is securely positioned and anchored.

It is sometimes easier to lash the bamboo along the third leg before the tripod is laid; the flag being stopped out of the way and fitted with a burster; on completion of rigging the tripod the heel of the bamboo can be manoeuvred into the centre of the tripod and held vertical by lashings to each of the legs of the tripod.

As the legs will probably settle on the bottom after a day or two it will be advisable

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* It is important that the heel weights are heavy enough to keep the legs well down. Large wooden spars give considerable flotation and it should be remembered that cast iron sinkers lose 10% of their weight in air when immersed in sea water. Concrete sinkers lose 40% of their weight in air until they become saturated with water when the percentage loss will not be so great.

LAYING A TRIPOD FROM A BOAT

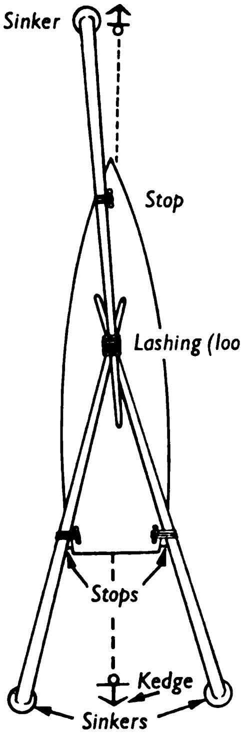


Fig. I-10

to visit the mark again and haul taut the guys; these should be so arranged that this can be done from the mark without disturbing the anchors.

Dismantling a mark of this nature is best done by securing a boat within the tripod just before low water. Rig tackles from the gunwhale of the boat to strops on each leg. Haul each leg up and towards the boat as far as possible, having first slacked the guys to the anchors.

It may be possible to lift all the legs well clear of the bottom in this way, but if not they should come clear as the tide rises. A second boat should then weigh the anchors. The boat with the tripod is then towed back to the ship where the tripod can be hoisted out and dismantled.

b. Erecting a pole mark from a boat

It is only worth while considering a barling (or other spar about 10 metres in length) for erecting from a boat. Smaller spars will only have sufficient height to be useful at high water if they are erected in very shallow water (2 metres and less at low water) and are best done by wading and swimming.

A boat (about 10 metres long) and dinghy are required.

Secure the pole in the boat with its heel and heelweight (50 kilos) projecting over one bow. Two wire strops with four small blocks are secured to the pole just about the level of high water on the pole when it is erected.

Anchor the boat head and stern over the selected site in the direction of the stream. Reeve the four wire guys through the four blocks on the pole. Keeping these guys clear, lower the heel of the pole over the bows to the bottom and stop the head of the pole temporarily to the boat in an upright position. If a top-mark and flag is required these must be lashed on while the pole is horizontal and the flag stopped and fitted with a burster.

From the dinghy lay out the four anchors and wire guys attached. One pair at right angles to the main directions of the stream and the other pair in the line of the streams.

The anchors must be laid at a distance not less than five times the height of the pole from heel to the strops and care taken that they are laid clear of the boat's anchors.

Haul taut on the guys as necessary to get the pole vertical. The process of adjusting will be simplified if improvised cleats are made on the pole with large nails.

The above operation is similar to that for erecting a tide pole off shore (*see* Chapter 2, Section **8a**(v)).

c. Erecting a pole mark on a reef

This can be rigged as on land using anchors or stakes as necessary, but the structure must be stronger and firmer to withstand the action of wind and waves.

d. Erecting a mark in soft mud

In soft mud, small marks may sometimes be 'planted' in shallow water from a boat. If up to about 2 metres of pole can be thrust or screwed into the mud the mark will probably stand for a considerable time.

17. Floating Beacons

Fig. 1–11 shows the parts of the Admiralty Standard Surveying Beacon.

Before the introduction of electronic fixing systems, floating surveying beacons were the only means available for extending surveys out of sight of land. This can be done by laying numerous beacons in a pattern and connecting them to a shore triangulation system as described in Volume 1, Chapter 5, Sections **8** and **9**. For areas of small extent in depths of from 8 to 60 metres this use of floating beacons may still be useful because of the saving in time compared with setting up the control with an electronic system (a ships outfit of six floating beacons providing visual/radar control over 300 square miles can normally be laid and fixed in the daylight hours of a single day), but in general their use is tending to become restricted to oceanic surveys and to providing datum reference positions for electronic systems.

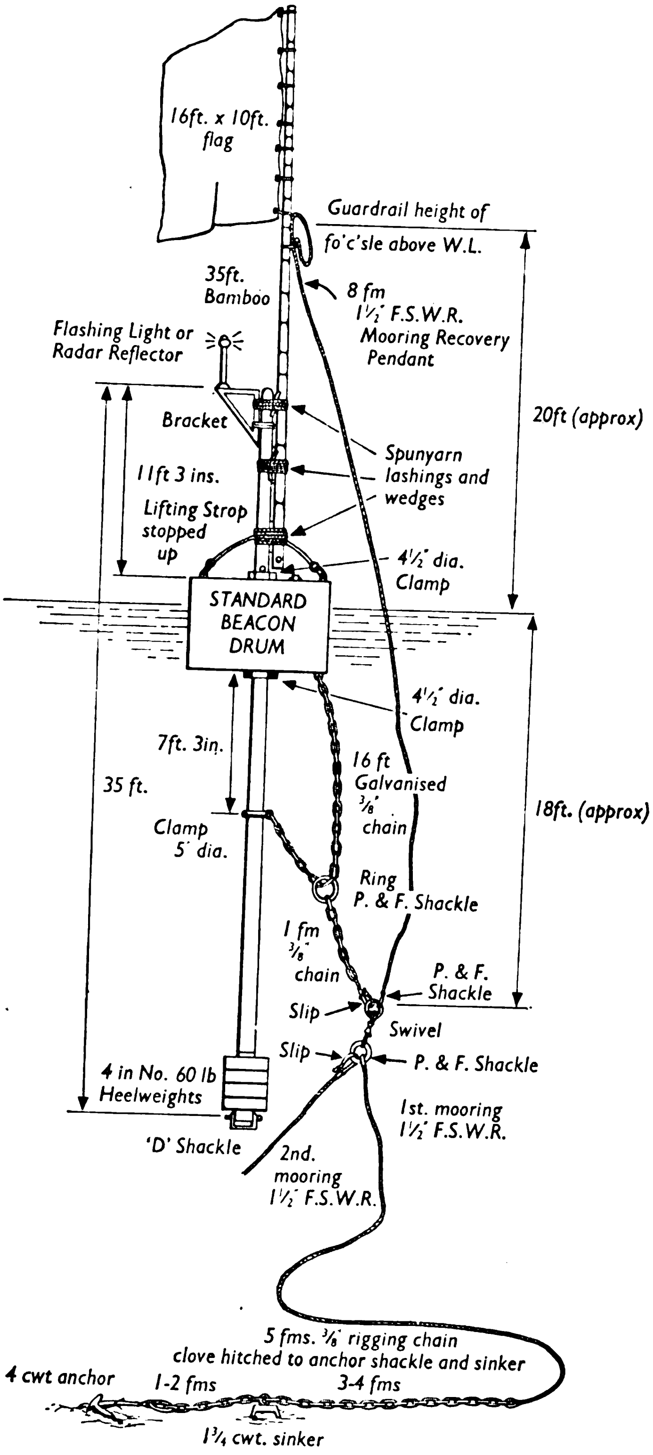
The beacon is rigged on the forecastle ready for laying. The details of the rigging can be seen from Fig. 1–11 and should require no further explanation other than that the flag is furled and stopped up with cotton. It is broken out with a smiting line as soon as the beacon has been laid. It is most important that all shackles are securely fastened. The forelocks of pin and forelock shackles must be in good condition and the pins of screw shackles must be securely moused with strong seizing wire.

A beacon may be laid either with a single mooring, when it has a relatively large swinging circle, or with a double mooring, when the swinging area is reduced to an ellipse. The swinging circle will also depend on the depth of water in which the beacon is laid and the scope of the moorings. The latter will depend on the tidal range in the area and the maximum strength of the tidal stream or current likely to be expected. Because of the size of their swing, beacons should not normally be used in surveys whose scale is greater than about 1/36,000.

Beacons with double moorings should be used wherever the lengths of moorings required are not too great for the flotation of the drum.

For small-scale surveys and those in deep water, single mooring beacons may be used. *See* Section **19** regarding length of moorings.

Each mooring is usually made up of 1½-inch F.S.W.R. with ground tackle consisting of a 100 kilo sinker connected to a 200 kilo beacon anchor by about 10 metres of ⅜-inch chain. The length of mooring used should normally be about 1¼ to 1½ times the depth of water at high water springs, depending on the maximum rate of the tidal stream. In very deep water, oceanographical wire may be used for the mooring wire. For very deep moorings,


16ft. x 10ft. flag
Guardrail height of fo'c'sle above W.L.
35ft. Bamboo
8 fm 1½" F.S.W.R. Mooring Recovery Pendant
Flashing Light or Radar Reflector
20ft (approx)
Bracket
Spunyarn lashings and wedges
11ft 3 ins.
Lifting Strop stopped up
4½" dia. Clamp
STANDARD BEACON DRUM
4½" dia. Clamp
7ft. 3in.
35 ft.
16 ft Galvanised ⅜" chain
18ft. (approx)
Clamp 5" dia.
Ring P. & F. Shackle
1 fm ⅜" chain
P. & F. Shackle
Slip
Swivel
Slip
P. & F. Shackle
4 in No. 60 lb Heelweights
1st. mooring 1½" F.S.W.R.
'D' Shackle
2nd. mooring 1½" F.S.W.R.
5 fms. ⅜" rigging chain clove hitched to anchor shackle and sinker
4 cwt anchor
1-2 fms
3-4 fms
1¾ cwt. sinker

STANDARD SURVEYING BEACON

Fig. 1-11

the reserve buoyancy of the beacon, which is 544 lbs (247·3 kilos approx.) must be considered and it may be necessary to provide an additional drum for extra flotation.

An approximate formulae for the calculation of the weight of steel wire rope in air is:

$$(\text{circumference in inches})^2 = \text{weight per fathom in pounds.}$$

A 20% reduction in weight should be allowed for the weight in sea water. Additional information on weights and strengths of cordage wire and rigging items will be found in Appendices to *Admiralty Manual of Seamanship*, Volume II.

While the beacon is being rigged, the moorings may be prepared ready for slipping. With a single mooring, the anchor and sinker are hung outboard from a slip through the forward fairleads and the mooring led outboard. The slack of the mooring wire should be made up into small coils and stopped to the top guard rail on the forecastle.

A derrick or crane is used to hoist the beacon out; the whip being attached to the lifting strop on the drum with a tripping hook. The heel of the beacon is hoisted out using a davit or derrick positioned further aft. The end of the mooring wire is then shackled to the swivel on the lower ring of the mooring bridle on the beacon. The beacon is then ready for laying.

On arrival at the laying position, the ship is stopped while heading into the stream or wind, and the beacon lowered until the drum is just clear of the water. The coils of mooring wire stopped to the guardrail are then cut free and held in hand. With a little sternway on the ship, the anchor and moorings are slipped and the mooring wire paid out, coil by coil. Finally, the beacon itself is slipped; as it draws clear ahead of the ship, the flag is broken out with the smiting line. Alternatively, the beacon can be slipped first, the mooring paid out and the anchor and sinker slipped last.

In deep water great care is necessary if the anchor is let go first as the wire will run out fast and there is a risk of foul turns developing with consequent danger to personnel. Some form of winch should preferably be used, but generally it is better to lower the beacon into the water first and pay out the mooring wire as ship and beacon drift away from each other.

When laying two moorings, the second anchor and mooring should be rigged aft of the beacon and hung through a suitable fairlead. The second mooring is shackled to the same ring on the bridle as the first mooring.

When laying a beacon with two moorings it is important to lay these in the direction of the prevailing wind or tidal stream, whichever is the stronger. The first anchor and mooring and the beacon itself should be slipped as described above. The ship should then be allowed to drift down wind or tide, assisted by the main engines if necessary. As the strain comes on the second mooring the anchor is slipped, thus ensuring a taut moor up and down tide. Where there is a strong tidal stream and/or a large rise and fall of tide care must be taken not to moor the beacon too taut or it will not watch during the strength of the stream, or at high water.

To weigh a beacon, a recovery wire (about 40 metres long) with a spring hook at one end is rove through one of the forward fairleads or bull ring; roller fairleads are best if the moorings are not to be crippled. The ship comes up to the beacon and the spring hook is clipped into the eye of the recovery pendant which is stopped to the bamboo at guardrail height. The recovery wire is heaved in and the eye of the recovery pendant cut loose from its stopping. The recovery pendant is heaved inboard by winch until the first ring of the mooring bridle is inboard. Meanwhile the derrick or crane should be plumbed over the side and the whip is clipped on to the beacon's lifting strop by a Davey hook shackled on to its end. The slip on the mooring bridle is then slipped and moorings and beacon are brought inboard independently. Care must be taken to prevent a heavy sideways strain being put on the derrick before the bridle slip is knocked off. With two moorings, they can both be weighed together on the same recovery wire or, if preferred, weighed separately, a second recovery wire being used.

A smaller version of the standard beacon is available for use with Inshore Survey Craft.

Floating beacons and dan buoys can be fitted with battery-operated quick flashing lamps to prevent shipping running down these marks at night. They have a very short range, generally less than five miles, and are supplied with white, red or green lights.

Radar reflectors are commonly fitted to beacons. If fixing is to be by radar, it is advisable to fit two reflectors, one at twice the height of the other. (*See also* Chapter 3, Section 18a(ii).)

Normal Method of Rigging a Danbuoy.

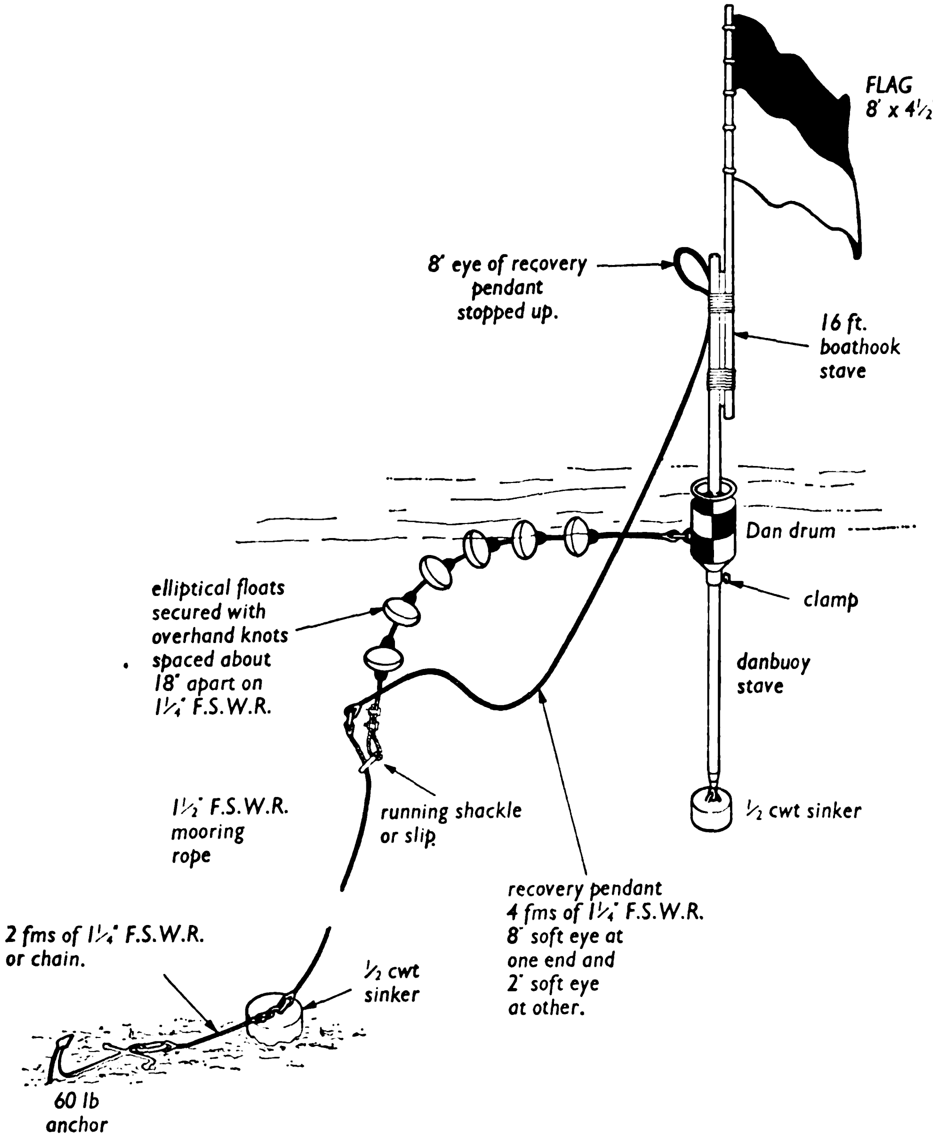

FLAG
8' x 4½'
8" eye of recovery pendant stopped up.
16 ft. boathook stave
Dan drum
clamp
elliptical floats secured with overhand knots spaced about 18" apart on 1¼" F.S.W.R.
danbuoy stave
½ cwt sinker
1½" F.S.W.R. mooring rope
running shackle or slip
recovery pendant 4 fms of 1¼" F.S.W.R. 8" soft eye at one end and 2" soft eye at other.
2 fms of 1¼" F.S.W.R. or chain.
½ cwt sinker
60 lb anchor

Fig. 1-12

18. Dan Buoys

A dan buoy, fitted with naval pattern items, is shown, complete with moorings, in Fig. 1–12.

Dan buoys can be used in place of floating beacons where they are not required to be seen for distances greater than about three miles and in depths where their flotation is sufficient to support the moorings. They can be moored with double or single moorings in the same way as beacons. More often dan buoys are used with a single mooring as a temporary mark on a newly-found obstruction or for wreck sweeping purposes (*see* Chapter 4, Section **13**). If it is only required to be seen for a mile or so, a small commercial-type fishermen's 'polyform' (inflatable) dan buoy can be used. With this smaller type of dan buoy, moorings can be made up from 1½-inch cordage and a ½-cwt. sinker, backed up, if necessary, with a small anchor. This type of dan buoy has the great advantage that it can be laid and weighed easily from a boat.

The can of a full-size dan buoy has a total buoyancy of about 106 lbs. To provide extra buoyancy to carry the moorings in a tideway, a span of elliptical floats is fitted as shown in Fig. 1–12. These floats have a buoyancy of 30 lbs each and the number required will depend on the weight of the moorings used and the maximum strength of the tidal stream or current. In very deep water, or in strong streams a 'double dan' can be rigged with two drums on the stave and double heelweights to provide greater stability. If more flotation is required, some of the elliptical floats can be replaced by dan drums. To facilitate recovery the span of pellets is secured to the mooring by means of a running shackle or slip.

For length of mooring, *see* Section **19**.

A dan buoy is usually laid from aft, the anchor and sinker being hung outboard through an after fairlead and the dan buoy hung from a tripping hook on a whip from the minesweeping davit, the mooring being led outboard. The dan buoy is normally laid underway by first slipping the dan buoy itself, then paying out all the mooring until the dan buoy is being towed astern and then finally slipping the anchor and sinker when in the laying position.

Dan buoys can be weighed from aft or forward, as desired, the picking up wire being clipped into the eye of the recovery pendant as with a beacon. When being recovered from aft, great care must be taken to ensure that the moorings do not foul the propellers.

19. Lengths of Moorings for Beacons and Dan Buoys

For nearly all surveying work it is desirable for floating marks to have as little movement in the lateral plane as possible. To achieve this depends upon keeping the moorings as short as possible. There are four main factors which control the length of the mooring.

(i) The depth of water at high water.

(ii) Angle of pull on the anchor and sinkers to prevent lifting off the bottom under strain and dragging.

(iii) The flotation available from the beacon drum.

(iv) The strength of the tidal stream or current.

The factor at (i) is easily allowed for and in conditions of calm weather, no streams and a heavy anchor the length of mooring need only be fractionally greater than the depth of water to allow for minor errors of measurement.

No precise rules can be given for the angle of pull on the anchor as this depends to a large extent on the nature of the bottom and the weight of the ground tackle. The heavier the ground tackle the more the angle of the mooring wire may approach the vertical. In general an angle of pull of 30° to the horizontal will be satisfactory for ground tackle weighing not less than 300 kilogrammes for a beacon, and 150 kilogrammes for a dan buoy.

The factors at (iii) and (iv) above become increasingly important in water deeper than

30 metres (16 fathoms approx.), or when the tidal streams are likely to exceed 3 knots. In these conditions the length of mooring required can be obtained from the curves in Figs. 1-14 and 1-15 for beacons, and 1-16 and 1-17 for dan buoys. These curves have been drawn from calculations based upon the formulae given below.

For a single mooring:

$$l = d \sec. \psi. \tag{1}$$

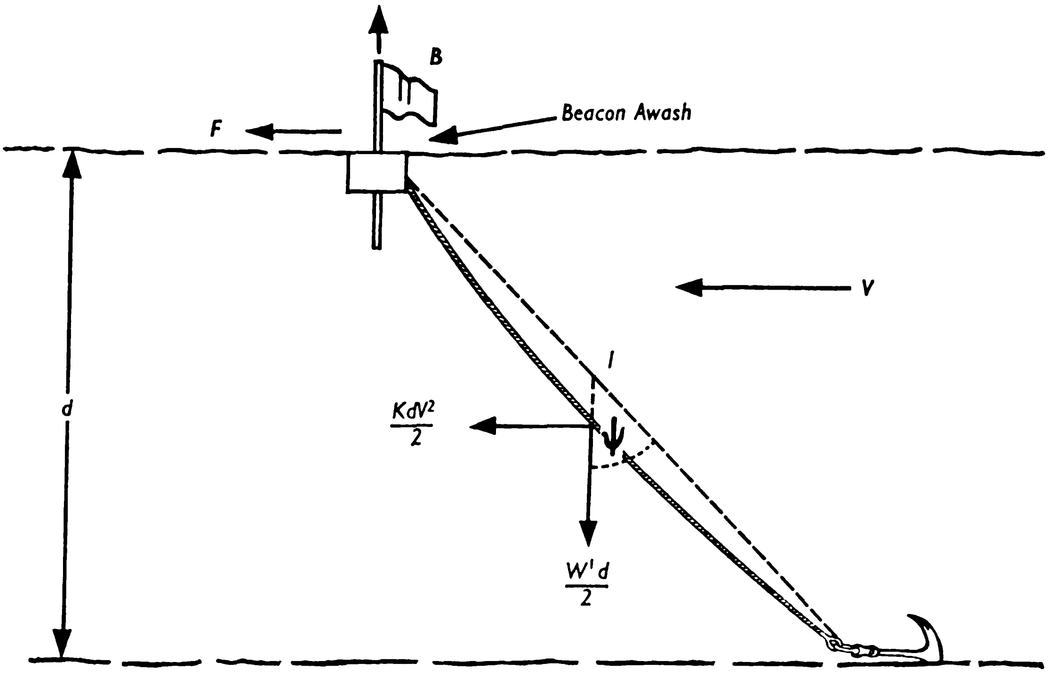
$$\text{Tan } \psi = \frac{(F + \frac{1}{2} KdV^2)}{(B - \frac{1}{2} W'd)} \tag{2}$$

and for a double mooring:

$$\text{Tan } \psi = \frac{(F + 1{\cdot}5\, KdV^2).}{(B - 1{\cdot}5\, W'd)} \tag{3}$$

Where in Fig. 1-13

l is the length of mooring required in fathoms
d is the depth of water at high water springs in fathoms
ψ is the angle of slope to the vertical of the mooring wire, assuming that the mooring is a straight line
F is the drag on the beacon at the tidal stream rate concerned
K is a constant (*see* below)
B is the *reserve* buoyancy of the beacon drum without mooring but fully rigged.
W' is W sec. ψ where W is the weight of a unit length of the wire in water
V is the rate of the tidal stream in knots.



Floating Beacon. Length of Mooring

Fig. 1-13

In developing these formulae the problem has been considered for a beacon drum just awash and the following assumptions made.

That the maximum rate of the stream occurs at high water and that the velocity of the stream is uniform from surface to seabed. Friction of the stream along the mooring wire, together with sag in the wire, have been neglected.

These formulae are therefore only approximate, but should provide a useful guide for obtaining the length of mooring required in strong streams.

In the above formulae:

$$F = \frac{1}{2g} \times 1{\cdot}1\,\rho A V^2 \quad \text{and} \quad KV^2 = \frac{1{\cdot}1\,\rho b}{2g} \times V^2.$$

Where ρ is the mean density of sea water

A is the cross sectional area of a cylindrical drum

b is the *diameter* of the wire.

These formulae should be calculated in foot-lb-sec. units where the mean density of sea water (specific gravity 1·025) is about 64 lbs/cub. ft., 1 knot is 1·69 ft./sec.

A Standard Beacon consists of a cylindrical drum 3 feet in diameter and 2 feet high and has a spar 5 inches in diameter protruding 22 feet through the bottom. It has a reserve buoyancy of 544 lbs. The mooring wire used is normally 1½ inches (circumference) F.S.W.R. which weighs 1·5 lbs per fathom in air. The specific gravity of steel is about 7·8.

Therefore:

$$B = 544 \text{ lbs.}$$

$$A = 15{\cdot}2 \text{ sq. ft.}$$

$$F = \frac{1{\cdot}1 \times 64 \times 15{\cdot}2}{2 \times 32{\cdot}2} \times (1{\cdot}69\,V)^2 = 47{\cdot}5\,V^2 \ (V \text{ in knots})$$

$$b = \frac{3}{24\pi} \text{ ft.} = 0{\cdot}040 \text{ ft.}$$

$$W = \frac{7{\cdot}8 \times 1{\cdot}5 - 1{\cdot}5}{7{\cdot}8} = 1{\cdot}3 \text{ lbs per fathom}$$

$$KV^2 = \frac{1{\cdot}1 \times 64 \times 0{\cdot}040 \times 6}{2 \times 32{\cdot}2} \times (1{\cdot}69\,V)^2 = 0{\cdot}75\,V^2 \text{ lb/fm.}$$

The formulae can also be applied to a case where a beacon is backed up by an additional drum to add to the buoyancy in strong streams or very deep water, provided the drums are a few yards apart and there is therefore no sheltering effect.

For a single mooring:

$$\operatorname{Tan} \psi = \frac{(F + F' + \tfrac{1}{2}\,KdV^2)}{(2B - \tfrac{1}{2}\,W'd)} \tag{4}$$

and for a double mooring:

$$\operatorname{Tan} \psi = \frac{(F + F' + 1{\cdot}5\,KdV^2)}{(2B - 1{\cdot}5\,W'd)} \tag{5}$$

where F' is the drag on a drum without a spar at the rate concerned. The second drum will also, in fact, have a buoyancy greater than the normal reserve buoyancy as it will not be carrying a spar, flag, heel-weights, etc. However, if its buoyancy is considered to be the normal reserve buoyancy, the calculated length of mooring will be on the safe (long) side.

In the same way, the approximate formula for a single mooring can be applied to a dan buoy:

$$\operatorname{Tan} \psi = \frac{(F + F'' + \tfrac{1}{2}\,(x-1)\,F'' + \tfrac{1}{2}\,KdV^2).}{(B + Bx - \tfrac{1}{2}\,W'd)} \tag{6}$$

Where F is the drag on the dan buoy drum and stave at the rate considered
F'' is the drag on a single float at that rate
B is the reserve buoyancy of the dan buoy drum
B' is the buoyancy of each float
and x is the number of floats used.

Equation (6) makes an approximate allowance for the sheltering effect caused by the first float. The formula for the drag on an elliptical float or pellet is:

$$F'' = \frac{1}{2g} \times 0\cdot5\,\rho\, AV^2.$$

In this case, $A = \pi ab$, where a is the semi-major axis and b is the semi-minor axis of the ellipse.

In using the above formulae (2) to (6) it will be seen that it is first necessary to calculate ψ in order to find l. In doing this, it is first necessary to find W' and this in turn requires a knowledge of the angle ψ. Since $\frac{1}{2}\,W'd$ is numerically much smaller than B in practice, the equation can be conveniently solved by first finding ψ with $W' = W$ and then using this value of ψ to give a better approximation of W' and hence ψ and so on, if necessary. Except when dealing with problems in deep water with strong streams, the second approximation is usually sufficiently accurate to give a satisfactory answer. If it is impossible to find the value of W' in this way as its value increases rapidly with each approximation, then it is an indication that it is impractical to lay the beacon or dan buoy under the conditions concerned. Extra buoyancy is therefore required or the drag and weight must be decreased by using a smaller mooring wire.

The top expression for each of the formulae for ψ gives the drag on the complete rig and mooring and these offer an indication of the force applied to the anchor and sinker under the extreme conditions considered. These should give an idea of whether the ground gear to be used is likely to be sufficient to prevent the beacon from dragging. If the horizontal pull required to drag a beacon anchor and sinker over good and poor holding ground can be obtained by experiment, then a more precise idea can be obtained for the amount of ground gear required for the conditions concerned. The force required to drag an anchor is, however, rather complicated and will depend on its horizontal and vertical components. It is therefore partly dependent on the angle that the mooring makes with the vertical (ψ).

The actual expressions for the force components on the anchor are:

Horizontal: $F + KdV^2 \cos^2 \psi$.
Vertical: $B - Wd \sec. \psi - KdV^2 \cos \psi \sin \psi$.

Examples of calculated mooring problems

Example 1. (Simple problem as used to calculate points on the attached curves.) What is the length of mooring required to lay a Standard Beacon in 20 fathoms with a maximum tidal stream of 3 knots using a single mooring? What would be the maximum possible radius of swing of the beacon if the range of the tide is 15 feet? Mooring: 1½ inches F.S.W.R.

Data: $B = 544$ lbs
$F = 47\cdot5\ V^2$ lbs
$KV^2 = 0\cdot75\ V^2$ lb/fathom
$W = 1\cdot3$ lb/fathom.

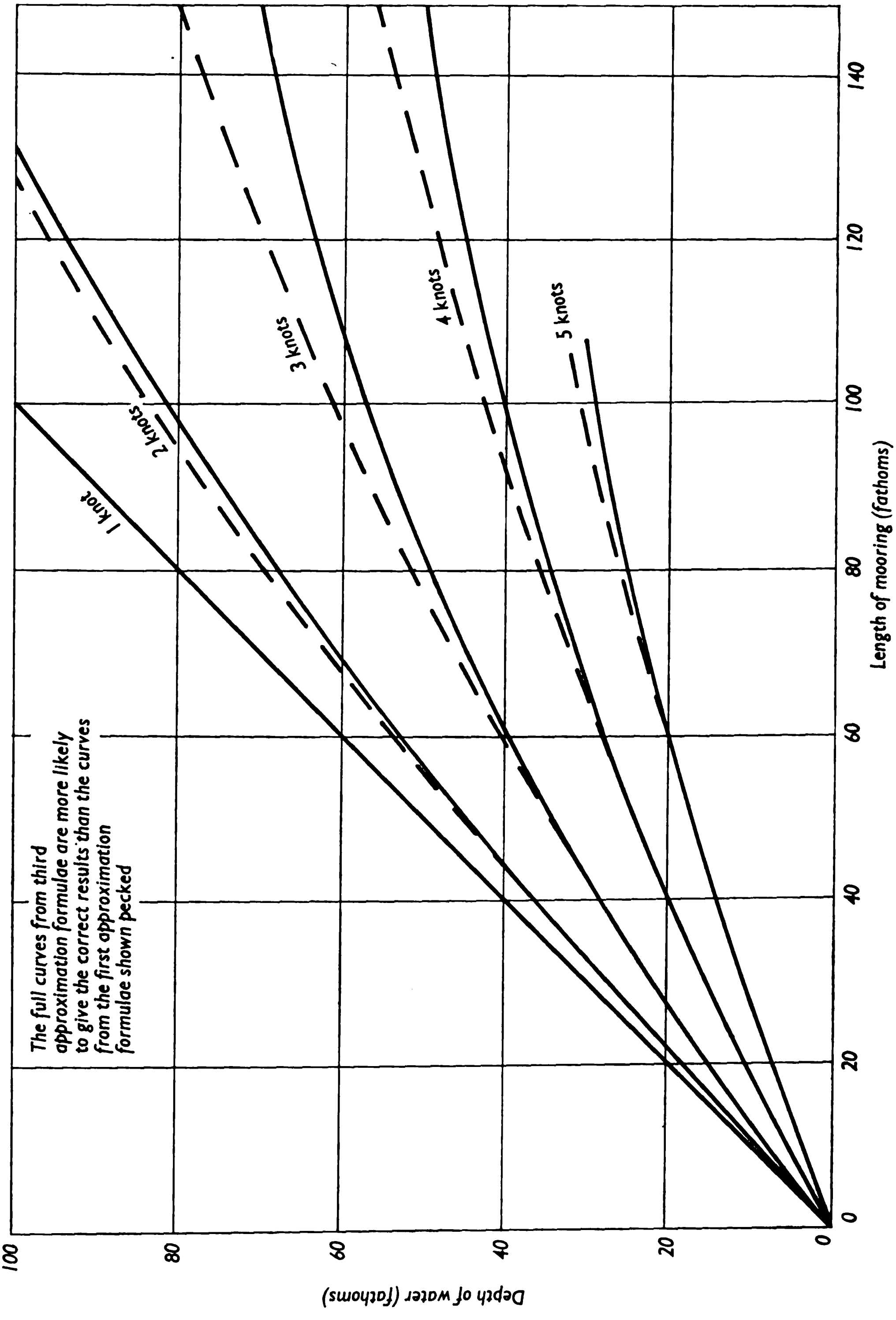
1st approximation, with $W' = W$:

$$\text{Tan}\ \psi = \frac{(F+\frac{1}{2}\,KdV^2)}{(B-\frac{1}{2}\,W'd)} = \frac{(47\cdot5\times9+0\cdot75\times9\times20\times\frac{1}{2})}{(544-1\cdot3\times20\times\frac{1}{2})} = \frac{495\cdot0}{531\cdot0}$$

$$= 0\cdot9322$$

$$\psi = 42^\circ\ 59' \text{ and } \cos \psi = 0\cdot7315.$$

Curves showing the MINIMUM length of 1½" F.S.W.R. single mooring required to lay an Admiralty Standard Beacon in varying depths with tidal streams of 1 to 5 knots.



The full curves from third approximation formulae are more likely to give the correct results than the curves from the first approximation formulae shown pecked

Fig. 1-14

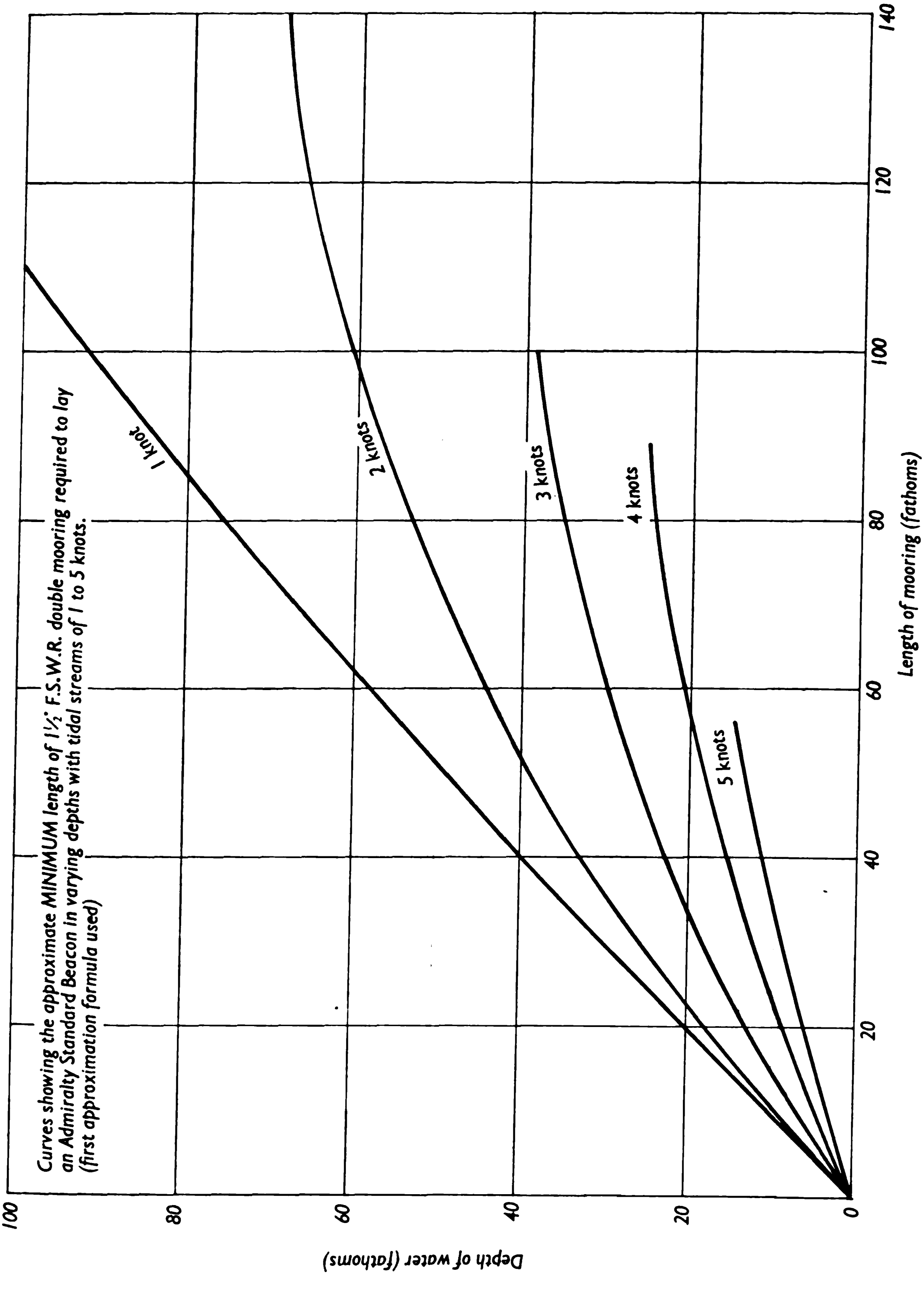
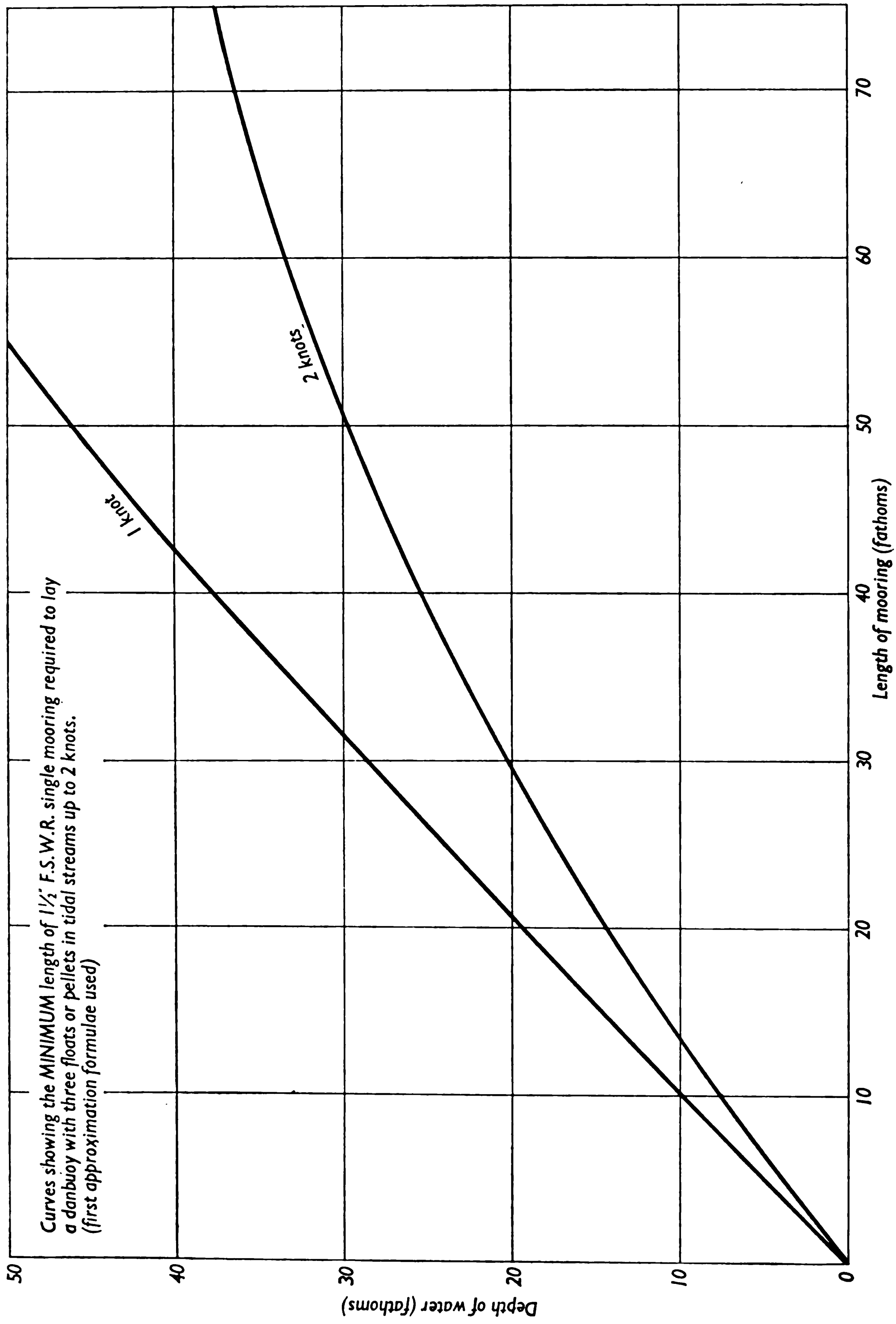

Curves showing the approximate MINIMUM length of 1½" F.S.W.R. double mooring required to lay an Admiralty Standard Beacon in varying depths with tidal streams of 1 to 5 knots.
(first approximation formula used)
1 knot
2 knots
3 knots
4 knots
5 knots
Length of mooring (fathoms)
0
20
40
60
80
100
120
140
Depth of water (fathoms)
0
20
40
60
80
100

Fig. 1-15



Curves showing the MINIMUM length of 1½" F.S.W.R. single mooring required to lay a danbuoy with three floats or pellets in tidal streams up to 2 knots.
(first approximation formulae used)

Fig. 1-16

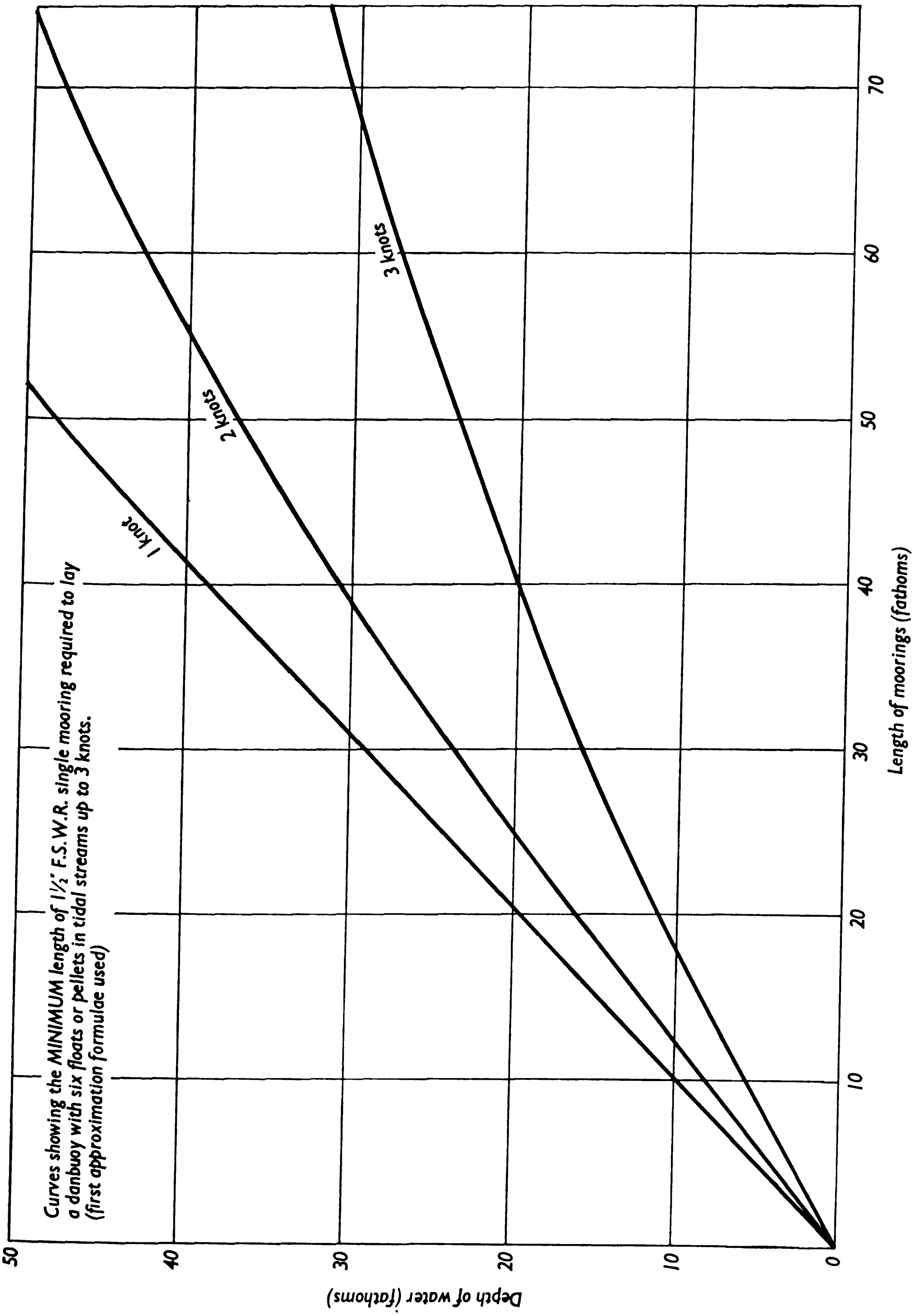

Curves showing the MINIMUM length of 1½" F.S.W.R. single mooring required to lay
a danbuoy with six floats or pellets in tidal streams up to 3 knots.
(first approximation formulae used)
1 knot
2 knots
3 knots
0
10
20
30
40
50
60
70
Length of moorings (fathoms)
0
10
20
30
40
50
Depth of water (fathoms)

Fig. 1-17

2nd approximation:

$$W' = \frac{1\cdot 3}{0\cdot 7315} = 1\cdot 77.$$

$$\begin{aligned}
\text{Tan } \psi &= \frac{495\cdot 0}{(544-17\cdot 7)} = \frac{495\cdot 0}{526\cdot 3} = 0\cdot 940\,528 \\
\therefore \psi &= 43^\circ\ 14' \text{ and } \cos \psi = 0\cdot 728\,437 \\
\therefore W' &= \frac{1\cdot 3}{0\cdot 728\,437} = 1\cdot 78, \text{ so 3rd approximation not required} \\
\therefore l &= \frac{20}{0\cdot 728\,437} = 27\cdot 45 \text{ fathoms}
\end{aligned}$$

Therefore a 28-fathom mooring, at least, should be used.

To calculate radius of swing

Depth of water at high water = 20 fathoms, so depth at low water = 17·75 fathoms.

$$\text{Cos } \psi_1 = \frac{17\cdot 75}{28} = 0\cdot 633\,92, \text{ so } \psi_1 = 50^\circ\ 39' \text{ and Tan } \psi_1 = 1\cdot 219\,02$$

Radius of maximum swing = $17\cdot 75 \text{ Tan } \psi_1$ = 21·6 fathoms = 43·2 yards.

Example 2. What is the minimum length of each mooring for a Standard Beacon laid with double moorings in a depth at high water of 35 fathoms with an expected maximum tidal stream of 4 knots? An extra beacon drum is to be added to provide extra buoyancy.

Data: As for example 1 and $F' = \frac{1\cdot 1 \times 64 \times 6}{2 \times 32\cdot 2} \times (1\cdot 69\ V)^2 = 18\cdot 73\ V^2$ lbs.

1st approximation with $d = 35$, $V = 4$ and $W' = 1\cdot 3$:

$$\begin{aligned}
\text{Tan } \psi &= \frac{(F+F'+1\cdot 5\ KdV^2)}{(2B-1\cdot 5\ W'd)} = \frac{47\cdot 5 \times 16 + 18\cdot 73 \times 16 + 1\cdot 5 \times 0\cdot 75 \times 16 \times 35}{1088 - 1\cdot 5 \times 1\cdot 3 \times 35} \\
&= \frac{1689\cdot 6}{1019\cdot 75} = 1\cdot 656\,87 \\
\therefore \psi &= 58^\circ\ 53' \text{ and } \cos \psi = 0\cdot 516\,73.
\end{aligned}$$

2nd approximation:

$$\begin{aligned}
W' &= \frac{1\cdot 3}{0\cdot 516\,73} = 2\cdot 52, \text{ so taking } W' \text{ as } 2\cdot 6 \text{ (the next } 0\cdot 1 \text{ higher)}, \\
\text{Tan } \psi &= \frac{1689\cdot 6}{(1088 - 1\cdot 5 \times 2\cdot 6 \times 35)} = 1\cdot 775\,72 \\
\psi &= 60^\circ\ 37' \text{ and } \cos \psi = 0\cdot 490\,69 \\
W' &= \frac{1\cdot 3}{0\cdot 490\,69} = 2\cdot 64, \text{ so 3rd approximation not required} \\
\text{and } l &= \frac{35}{0\cdot 490\,69} = 71\cdot 3 \text{ fathoms.}
\end{aligned}$$

Therefore length of mooring should be at least 72 fathoms.

Note. If this problem is worked out with only one drum, it will be found to be impossible to find W' as it will be continually and rapidly increasing with each approximation. This indicates that it is quite impracticable to lay a beacon with one drum under those conditions as it will be pulled under whatever the length of moorings used as the tidal stream reaches maximum rate.

Example 3. What is the minimum length of single mooring required for a dan buoy with a span of three pellets, to be laid in 10 fathoms with a maximum tidal stream of 2 knots, using $1\frac{1}{2}$ inch F.S.W.R. moorings?

Data: The total buoyancy of a dan drum is 106 lbs, so the reserve buoyancy, B, can be taken as 50 lbs.

Dimension of cylindrical drum: $2{\cdot}0 \times 1{\cdot}42$ ft.

Dan stave: 8 ft. below drum and 0·3 ft. diameter.

Elliptical float (pellet): Buoyancy, $B' = 30$ lbs.
Dimensions: $a = 1{\cdot}25$ ft., $b = 0{\cdot}75$ ft.

$A = 5{\cdot}24$ sq. ft.

$B = 50$ lbs.

$$F = \frac{1{\cdot}1 \times 64 \times 5{\cdot}24}{2 \times 32{\cdot}2} \times (1{\cdot}69\ V)^2 = 16{\cdot}36\ V^2 \text{ lbs.}$$

$KV^2 = 0{\cdot}75\ V^2$ lbs/fathom

Elliptical float: $A = \pi ab = 2{\cdot}95$ sq. ft.

$$F'' = \frac{0{\cdot}5 \times 64 \times 2{\cdot}95}{2 \times 32{\cdot}2} \times (1{\cdot}69\ V)^2 = 4{\cdot}17\ V^2 \text{ lbs}$$

$B' = 30$ lbs.

Mooring wire $W = 1{\cdot}3$ lbs/fathom.

1st approximation, with $W' = 1{\cdot}3$:

$$\text{Tan } \psi = \frac{(F + F'' + \frac{1}{2}(x-1)F'' + \frac{1}{2}\ KdV^2)}{(B + B'x - \frac{1}{2}\ W'd)}$$

$$= \frac{(16{\cdot}36 \times 4 + 4{\cdot}17 \times 4 + 1 \times 4{\cdot}17 \times 4 + 0{\cdot}5 \times 0{\cdot}75 \times 4 \times 10)}{(50 + 30 \times 3 - 0{\cdot}5 \times 1{\cdot}3 \times 10)}$$

$$= \frac{113{\cdot}80}{140{\cdot}0 - 6{\cdot}5} = \frac{113{\cdot}80}{133{\cdot}5} = 0{\cdot}852\,43.$$

$$\psi = 40^\circ\ 27' \text{ and } \cos \psi = 0{\cdot}761\,03.$$

2nd approximation:

$$W' = \frac{1{\cdot}3}{0{\cdot}761\,03} = 1{\cdot}7.$$

$$\text{Tan } \psi = \frac{113{\cdot}80}{140{\cdot}0 - 0{\cdot}5 \times 1{\cdot}7 \times 10} = \frac{113{\cdot}80}{131{\cdot}5} = 0{\cdot}865\,39$$

$$\therefore \psi = 40^\circ\ 52' \text{ and } \cos \psi = 0{\cdot}756\,17$$

$$\therefore W' = \frac{1{\cdot}3}{0{\cdot}756\,17} = 1{\cdot}71, \text{ so no 3rd approximation required.}$$

$$\therefore l = \frac{10}{0{\cdot}756\,17} = 13{\cdot}2 \text{ fathoms.}$$

A mooring of at least 14 fathoms should therefore be used.

20. Mark Boats

For a special purpose, such as extending a triangulation down a difficult stretch of coastline or across a wide strait or bay, it may be convenient to establish tautly moored temporary floating marks, which can be co-ordinated by simultaneous observations taken from ashore. This can be done with tautly moored beacons, but mark boats will be more satisfactory than dan buoys if the water is too shallow to lay a beacon.

A ship's whaler makes an excellent mark boat, although any suitable boat can be used. It should be moored head and stern in the direction of the stream with the mast stepped. To increase the visibility range a bamboo with a large surveying flag can be lashed to the mast. A four-point mooring may be used to reduce movement further. It is also easier to observe sextant angles or Tellurometer distances at the mast of a mark boat than from a boat alongside a floating beacon.

Mark boats will however require frequent baling out in rough or wet weather and should therefore not be left unattended for long periods.

21. Conversion Factors for Metric Units

1 Kilogramme = 2·20462 pounds avoirdupoids.
1 Pound (av) = 0·45359 kilogrammes.
1 International Nautical Mile = 1852 metres.

For other linear measurements *see* inside of covers.

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TABLE FOR CONVERTING METRES TO FEET AND FATHOMS

Metres	Feet	Fms.
1	3·281	0·547
2	6·562	1·094
3	9·843	1·640
4	13·123	2·187
5	16·404	2·734
6	19·685	3·281
7	22·966	3·828
8	26·247	4·374
9	29·528	4·921
10	32·808	5·468
11	36·089	6·015
12	39·370	6·562
13	42·651	7·108
14	45·932	7·655
15	49·213	8·202
16	52·493	8·749
17	55·774	9·296
18	59·055	9·843
19	62·336	10·389
20	65·617	10·936
21	68·898	11·483
22	72·178	12·030
23	75·459	12·577
24	78·740	13·123
25	82·021	13·670
26	85·302	14·217
27	88·583	14·764
28	91·864	15·311
29	95·144	15·857
30	98·425	16·404
31	101·706	16·951
32	104·987	17·498
33	108·268	18·045
34	111·549	18·591
35	114·829	19·138
36	118·110	19·685
37	121·391	20·232
38	124·672	20·779
39	127·953	21·325
40	131·234	21·872
41	134·514	22·419
42	137·795	22·966
43	141·076	23·513
44	144·357	24·059
45	147·638	24·606
46	150·919	25·153
47	154·199	25·700
48	157·480	26·247
49	160·761	26·794
50	164·042	27·340

Metres	Feet	Fms.
51	167·323	27·887
52	170·604	28·434
53	173·885	28·981
54	177·165	29·528
55	180·446	30·074
56	183·727	30·621
57	187·008	31·168
58	190·289	31·715
59	193·570	32·262
60	196·850	32·808
61	200·131	33·355
62	203·412	33·902
63	206·693	34·449
64	209·974	34·996
65	213·255	35·542
66	216·535	36·089
67	219·816	36·636
68	223·097	37·183
69	226·378	37·730
70	229·659	38·276
71	232·940	38·823
72	236·220	39·370
73	239·501	39·917
74	242·782	40·464
75	246·063	41·010
76	249·344	41·557
77	252·625	42·104
78	255·906	42·651
79	259·186	43·198
80	262·467	43·745
81	265·748	44·291
82	269·029	44·838
83	272·310	45·385
84	275·591	45·932
85	278·871	46·479
86	282·152	47·025
87	285·433	47·572
88	288·714	48·119
89	291·995	48·666
90	295·276	49·213
91	298·556	49·759
92	301·837	50·306
93	305·118	50·853
94	308·399	51·400
95	311·680	51·947
96	314·961	52·493
97	318·241	53·040
98	321·522	53·587
99	324·803	54·134
100	328·084	54·681

Metres	Feet	Fms.
200	656·17	109·36
300	984·25	164·04
400	1312·34	218·72
500	1640·42	273·40
600	1968·50	328·08
700	2296·59	382·76
800	2624·67	437·45
900	2952·76	492·13
1000	3280·84	546·81
2000	6561·68	1093·61
3000	9842·52	1640·42
4000	13123·36	2187·23
5000	16404·20	2734·03
6000	19685·04	3280·84
7000	22965·88	3827·65
8000	26246·72	4374·45
9000	29527·56	4921·26
10000	32808·40	5468·07

Metres	Inches
0·10	3·937
0·20	7·874
0·30	11·811
0·40	15·748
0·50	19·685
0·60	23·622
0·70	27·559
0·80	31·496
0·90	35·433
1·00	39·370

Factors: 1 metre = 3·280839895 feet or 39·370078740 inches
= 0·546806649 fathoms

N.P. 134 b (2)

ADMIRALTY MANUAL OF HYDROGRAPHIC SURVEYING

VOLUME TWO

CHAPTER 2

Tides and Tidal Streams

1969

Published by

THE HYDROGRAPHER OF THE NAVY
TAUNTON, SOMERSET

TABLE FOR CONVERTING FEET AND FATHOMS TO METRES

Feet	Fms.	Metres
1		0·305
1·5	¼	0·457
2		0·610
3	½	0·914
4		1·219
4·5	¾	1·372
5		1·524
6	1	1·829
7		2·134
8		2·438
9	1½	2·743
10		3·048
11		3·353
12	2	3·658
13		3·962
14		4·267
15	2½	4·572
16		4·877
17		5·182
18	3	5·486
19		5·791
20		6·096
21	3½	6·401
22		6·706
23		7·010
24	4	7·315
25		7·620
26		7·925
27	4½	8·230
28		8·534
29		8·839
30	5	9·144
31		9·449
32		9·754
33	5½	10·058
34		10·363
35		10·668
36	6	10·973
37		11·278
38		11·582
39	6½	11·887
40		12·192
41		12·497
42	7	12·802
43		13·106
44		13·411
45	7½	13·716
46		14·021
47		14·326
48	8	14·630
49		14·935
50		15·240

Feet	Fms.	Metres
51	8½	15·545
52		15·850
53		16·154
54	9	16·549
55		16·764
56		17·069
57	9½	17·374
58		17·678
59		17·983
60	10	18·288
61		18·593
62		18·898
63	10½	19·202
64		19·507
65		19·812
66	11	20·117
67		20·422
68		20·726
69	11½	21·031
70		21·336
71		21·641
72	12	21·946
73		22·250
74		22·555
75	12½	22·860
76		23·165
77		23·470
78	13	23·774
79		24·079
80		24·384
81	13½	24·689
82		24·994
83		25·298
84	14	25·603
85		25·908
86		26·213
87	14½	26·518
88		26·822
89		27·127
90	15	27·432
91		27·737
92		28·042
93	15½	28·346
94		28·651
95		28·956
96	16	29·261
97		29·566
98		29·870
99	16½	30·175
100		30·480

Feet	Fms.	Metres
102	17	31·090
108	18	32·918
114	19	34·747
120	20	36·576
126	21	38·405
132	22	40·234
138	23	42·062
144	24	43·891
150	25	45·720
156	26	47·549
162	27	49·378
168	28	51·206
174	29	53·035
180	30	54·864
186	31	56·693
192	32	58·522
198	33	60·350
204	34	62·179
210	35	64·008
216	36	65·837
222	37	67·666
228	38	69·494
234	39	71·323
240	40	73·152
246	41	74·981
252	42	76·810
258	43	78·638
264	44	80·467
270	45	82·296
276	46	84·125
282	47	85·954
288	48	87·782
294	49	89·611
300	50	91·440
306	51	93·269
312	52	95·098
318	53	96·926
324	54	98·755
330	55	100·584
336	56	102·413
342	57	104·242
348	58	106·070
354	59	107·899
360	60	109·728
366	61	111·557
372	62	113·386
378	63	115·214
384	64	117·043
390	65	118·872
396	66	120·701
402	67	122·530
408	68	124·358
414	69	126·187
420	70	128·016

Feet	Fms.	Metres
426	71	129·845
432	72	131·674
438	73	133·502
444	74	135·331
450	75	137·160
456	76	138·989
462	77	140·818
468	78	142·646
474	79	144·475
480	80	146·304
486	81	148·133
492	82	149·962
498	83	151·790
504	84	153·619
510	85	155·448
516	86	157·277
522	87	159·106
528	88	160·934
534	89	162·763
540	90	164·592
546	91	166·421
552	92	168·250
558	93	170·078
564	94	171·907
570	95	173·736
576	96	175·565
582	97	177·394
588	98	179·222
594	99	181·051
600	100	182·880

Feet	Metres
700	213·360
800	243·840
900	274·320
1000	304·800

Fms.	Metres
200	365·760
300	548·640
400	731·520
500	914·400
600	1097·280
700	1280·160
800	1463·040
900	1645·920
1000	1828·800

Inches	Ft.	Metres
1	0·083	0·025
2	0·167	0·051
3	0·250	0·076
4	0·333	0·102
5	0·417	0·127
6	0·500	0·152

Inches	Ft.	Metres
7	0·583	0·178
8	0·667	0·203
9	0·750	0·229
10	0·833	0·254
11	0·917	0·279
12	1·000	0·305

Factors

1 Inch = 0·0254 metres
1 Foot = 0·3048 metres
1 Fathom = 1·8288 metres or 6 feet

N.P.134 b (2)

ADMIRALTY MANUAL OF HYDROGRAPHIC SURVEYING

VOLUME TWO

CHAPTER 2

Tides and Tidal Streams

1969

Published by

THE HYDROGRAPHER OF THE NAVY

To be obtained from
Agents for the Sale of Admiralty Charts

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This Chapter supersedes the whole of Chapter XV of the *Admiralty Manual of Hydrographic Surveying* (1948 Edition).

Price 13*s*. 0*d*.

Printed in England for Her Majesty's Stationery Office
by The Campfield Press, St. Albans

FOREWORD

Part 1 of this Chapter deals with basic tidal theory, the establishment of tidal datums and practical harmonic analysis so far as it concerns the hydrographic surveyor.

Part 2 of the Chapter deals with the basic theory of tidal streams, practical methods of observation and analysis.

Reference is made to Volume I of the *Admiralty Manual of Hydrographic Surveying* (1965), the *Admiralty Tidal Handbooks* (Nos. 1, 2 and 3) and to the volumes of the *Admiralty Tide Tables*, and it is assumed that the reader will have access to these publications.

The text has been written by Commander H. R. Hatfield, R.N.

G. S. RITCHIE
Rear-Admiral
Hydrographer of the Navy.

CHAPTER 2

Tides and Tidal Streams

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CHAPTER 2 *Tides and Tidal Streams*

Part 1 Tides

1. Introduction

In order to make an accurate chart, the hydrographic surveyor must understand the characteristics of tides and allow for their vertical movements. In this chapter the basic theories of tides and the forces producing them will be discussed as simply as possible; relevant astronomical terms and terms used in connection with tides will be explained.

Tidal datums, to which depths and heights are referred, will also be described. From information given in this chapter the surveyor should be able to obtain a datum suitable for use in a hydrographic survey. He should, if possible, study *Admiralty Tidal Handbook No. 2, Datums for Hydrographic Surveys*, which covers this subject fully.

The principles of tidal analysis by harmonic methods will also be explained. Having grasped them, the surveyor should know what he must do in order to obtain satisfactory data for tidal analysis. A study of *Admiralty Tidal Handbooks Nos. 1 and 3, The Admiralty Semi-graphic Method of Harmonic Tidal Analysis (over a period of a month)* and *Harmonic Tidal Analysis for Short Period Observations*, is recommended. These publications not only develop the principles involved but also describe how tides are analysed using the appropriate forms.

The surveyor who wishes to go further into the subject of tides may also study *The Admiralty Manual of Tides.*

2. The Movements of the Sun and Moon

a. The sun

The sun may be considered to travel eastwards round the earth along a path known as the ecliptic. This path is shown in Fig. 2–1 as the ellipse *ABCD* whose plane is inclined to the celestial equator at an angle of about 23° 27′ (the obliquity of the ecliptic). The point where the ecliptic crosses the celestial equator from South to North at *B* is called the vernal equinox or the First Point of Aries ♈; the point of crossing from North to South at *D* (180° away) is called the autumnal equinox. At one point along the ecliptic the sun is at a maximum distance from the earth, while 180° away it is at a minimum distance; at these respective positions the earth is at aphelion and perihelion.

The sun completes its orbit in a year of about 365¼ days. During this time it passes through the positions of aphelion and perihelion; it also passes through points of maximum declination north at *C* and maximum declination south at *A*; these points are called the summer and winter solstices respectively. The sun crosses the equator in a northerly direction at the vernal equinox on about March 21 each year; it reaches the summer solstice on about June 22 and crosses the equator in a southerly direction at the autumnal equinox on about September 23. The winter solstice is reached on about December 22.

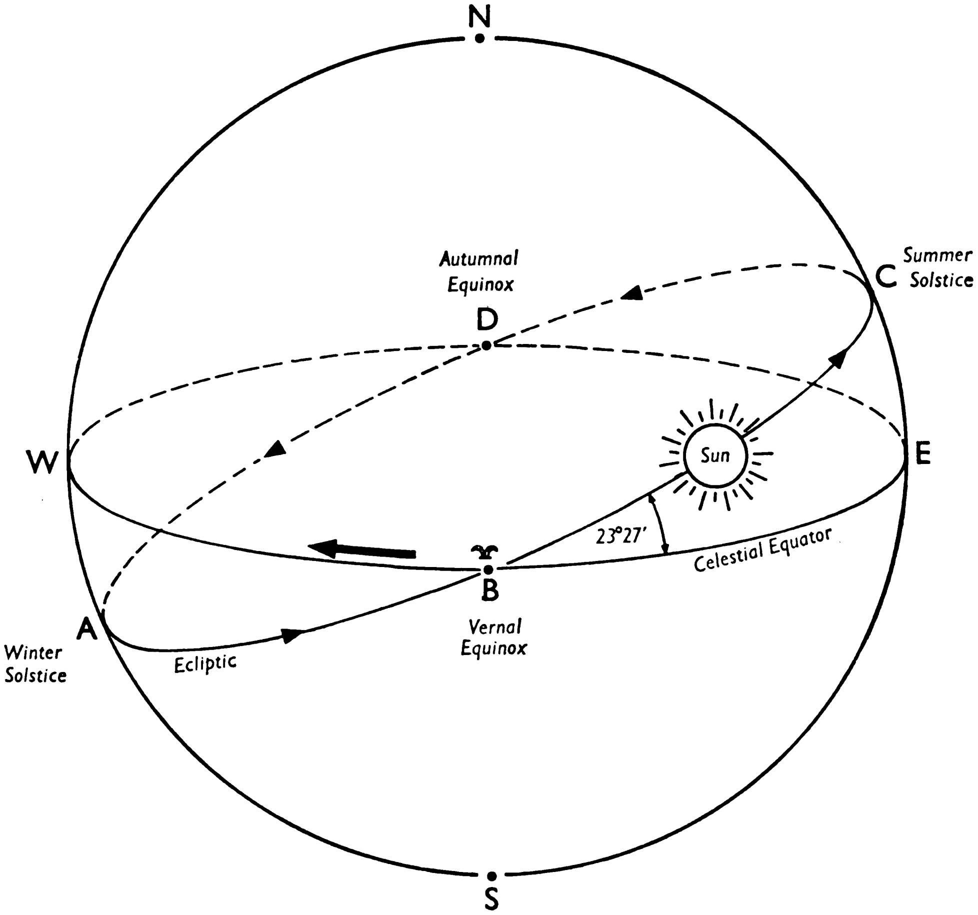

Fig. 2–1

For many practical purposes the sun's orbit may be considered to be fixed in space. It is affected, however, by small and continual changes, and this fact should not be forgotten. For example, the sun does not cross the equator at quite the same point each year; its movement is such that the position of the vernal equinox moves westwards round the celestial equator in the direction of the heavy arrow in a period of 26,000 years. This is called the Precession of the Equinoxes. The position of perihelion, which is now reached on about January 2 each year, also moves slowly round the ecliptic in the direction of the sun's movement in a period about five times as long as that of the Precession of the Equinoxes.

b. The moon

The moon may also be considered to move eastwards round the earth in an orbit similar to that of the sun. In Fig. 2–2 the ecliptic is shown as the firm ellipse *AKGCI*, while the moon's orbit is shown as the pecked line *GHIJK*. The plane of this orbit is inclined at about 5° 9′ to the plane of the ecliptic (this inclination varies from between 5° 0′ and 5° 17½′ over a period of time). The moon is much nearer the earth than is the sun, so its movement relative to an observer on the earth will be much faster, and any irregularities in that movement will be much more apparent.

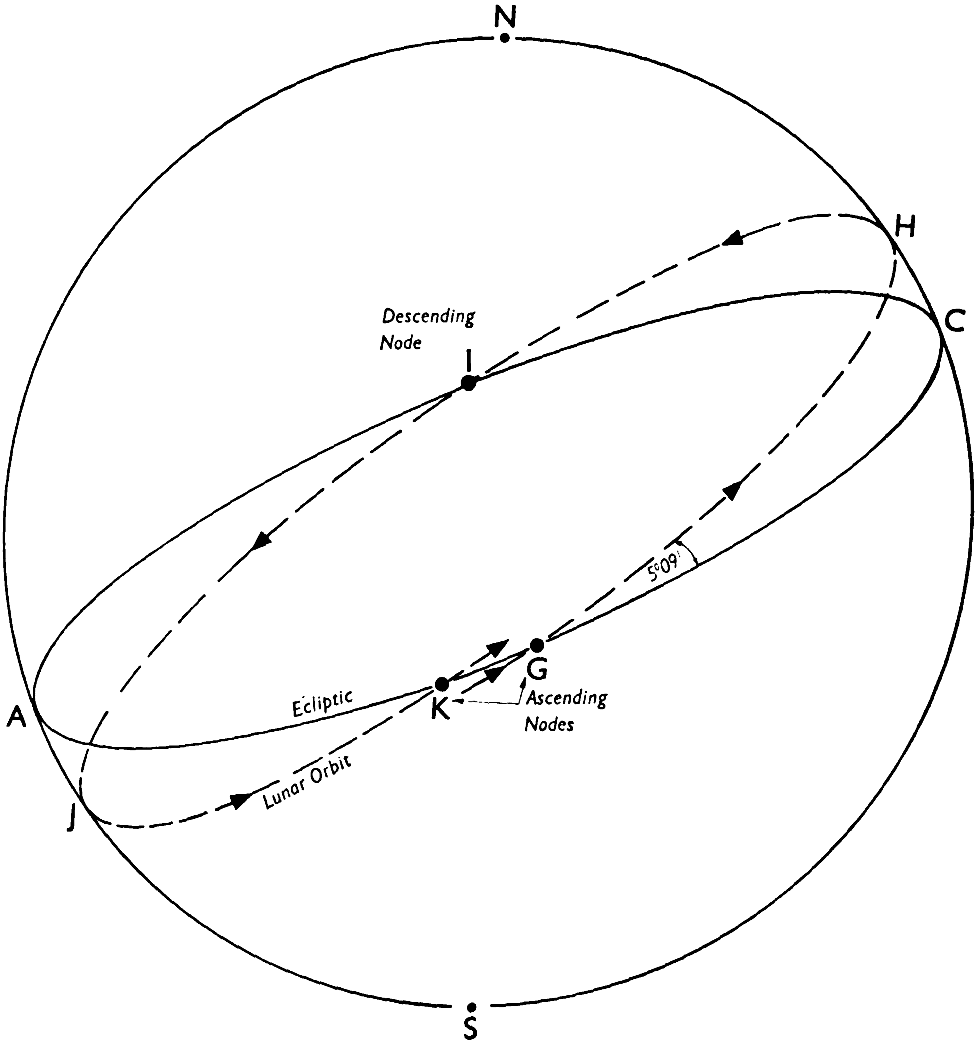

Fig. 2–2

(i) Motion of the moon's nodes. The points where the moon's path crosses the ecliptic are called nodes; the point where the moon crosses the ecliptic from south to north at *G* is called the ascending node, while *I* is called the descending node. The moon's orbit from the ascending node *G* to the next ascending node *K* takes 27·2122 mean solar days (the Draconitic Period). Measured relative to a fixed star the moon takes 27·3216 mean solar days to complete its orbit (the Sidereal Period). The movement of the nodes westwards along the ecliptic is called the regression of the nodes; it is analogous to the precession of the equinoxes along the equator but is much faster, having a period of 18·61 years. This is equivalent to 27·3216—27·2122 = 0·1094 days per orbit; in the diagram it is represented by the distance *KG*.

(ii) Perigee; apogee; declination. During the period of a lunar orbit, which is about 27$\frac{1}{3}$ mean solar days, the moon will, like the sun, reach positions of maximum declination north and south. It will also pass through a position of maximum distance from the earth called the apogee and a position of minimum distance from the earth known as the perigee; the period between perigee and successive perigee is 27·5546 mean solar days (the Anomalistic Period). Due to the regression of the nodes, the obliquity of the lunar orbit to the celestial equator will alter progressively with each orbit between a maximum and minimum value; the maximum obliquity will be the obliquity of the ecliptic plus the inclination of the lunar orbit to the ecliptic,* (i.e. about $23° 27' + 5° 9' = 28° 36'$), while the minimum obliquity will be the obliquity of the ecliptic minus the inclination of the lunar orbit to it (i.e. $23° 27' - 5° 9' = 18° 18'$). The maximum values of the moon's declination will therefore vary between these limits over the period of a complete cycle of the nodes which takes about 18·61 years.

(iii) The lunar day. The moon travels across the celestial sphere much faster than the sun, making about 13 complete orbits in one year. Since its motion is eastwards relative to the stars it will cross an observer's meridian later each day. The length of the 'lunar day' is about 24 hours 50 minutes.

(iv) The moon's phases. At one point during its orbit the moon's right ascension must be the same as that of the sun. If this should occur when the two declinations are also the same then at a point on the earth's surface between the earth's centre and the sun's centre the sun would be totally eclipsed by the moon. This exact situation rarely occurs, but near approximations occur at intervals of about 18 years 11 days (the Cycle of Saros); the length of this cycle is governed by a relationship between the cycle of the nodes and the period of lunation described below. When the moon's and the sun's right ascensions are the same, the moon is said to be new. Its illuminated edge, which faces the sun, will appear as a very narrow crescent.

When the moon's right ascension is 180° different from that of the sun it is said to be full; here again, if its declination is very nearly equal and opposite to that of the sun at that moment, the earth will be placed right in the path of the sun's rays; it will therefore cast a shadow on the moon's face, causing a partial or total eclipse of the moon. Usually, however, the declinations differ (in opposite senses) sufficiently for the moon to be fully illuminated by the sun.

Note that since the declination of a new moon is always very similar to that of the sun at the same time, whilst that of a full moon has a value similar to that of the sun, but in the opposite sense, the mid-winter full moon always reaches a very high meridian altitude.

When the moon has travelled right round its orbit, so that its right ascension again coincides with that of the sun, another new moon occurs. The period between successive new moons is called a lunation; owing to the relative speeds of the sun and moon in their orbits, it is a little longer than the period of a lunar orbit, being 29·5306 mean solar days; this period is sometimes referred to as the Synodic Period.

To an observer on the earth the new moon is best seen towards or shortly after sunset, as it is also setting. Each successive night the crescent will grow, until on about the seventh night the moon will appear as an illuminated half disc and will be on the observer's meridian at about 1800. The moon is then said to be in its first quarter. The luminous portion continues to increase until, on the fourteenth or fifteenth day, the full moon is on the meridian at about midnight. After full moon, its illuminated area decreases each succeeding night, until on about the twenty-second day only half the disc is illuminated; the moon is then said to be in its last quarter. When this occurs the moon is on the observer's meridian at about 0600. The terms new and full moon, first and last quarter are known as the phases of the moon.

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* This will occur where the moon's ascending node is at the First Point of Aries.

3. The Nature of Tides; Simple Basic Theory

a. The basic or semi-diurnal tide

The moon is much closer to the earth than the sun. According to Newton's law the force of gravity exerted by one heavenly body on another varies directly as its mass and inversely as the square of its distance from that body. However, the tide producing force varies directly as the mass of the body exerting the force, and inversely as the cube of the distance. Thus, despite its small size, the moon exerts a greater tide producing force than the sun; the proportion is about 11 : 5.

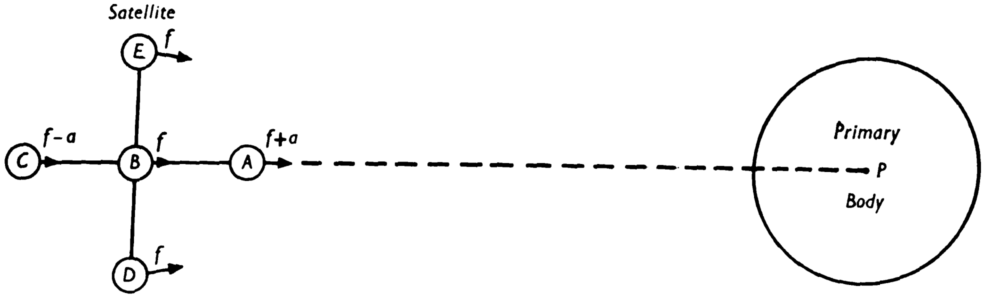

Fig. 2–3

In Fig. 2–3 a small satellite consisting of five identical billiard balls *A*, *B*, *C*, *D* and *E*, connected by two light but stiff rods of equal length which bisect each other at right angles at *B*, has just been launched into an orbit round the primary body *P*. The distance *BP* is very great compared with *CA* or *DE*. For convenience, all five billiard balls lie in the plane of the paper, and at the instant of observation they are stable in space (i.e. they are not rotating about *B*); *CA* produced passes through *P*.

Suppose that the attractive force of the primary, acting on *B*, is f. Then, since *A* is closer to the primary, the force acting on it will be $(f + a)$, in a direction towards the primary and parallel to f. At *C* the force will be $(f - a)$, and it will be parallel to the forces acting at *B* and *A*. As a result of these forces, the rod *CBA* will be stretched slightly; *A* will move towards the primary, and *C* away from it, until the tension in the rod is equal to $2a$.

At *D* and *E* the attractive forces of the primary will both be f, but these forces will be inclined inwards very slightly, as shown in the diagram, since they must act towards the centre of the primary. As a result the rod *DBE* will be compressed very slightly.*

If the primary body is the sun, and the satellite is a solid earth, which is not spinning on its axis, the latter will be deformed slightly. At points where the sun is in the zenith and the nadir the surface of the earth will move outwards; at all points where the sun is on the horizon, this movement will be inwards. It will be minute, but nevertheless just measurable with suitable instruments.

Now consider the earth to be covered with a layer of water, which is fluid. Clearly the water will be pulled outwards at points where the sun is in the zenith or the nadir, and inwards where the sun is on the horizon.

The same arguments may be applied to the earth-moon system, where the earth is in fact the primary body. Since the moon is so much closer than the sun, the forces involved will be larger.

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* This satellite will not in fact remain stable in space for long. It will start to rotate, so that the rod *CBA* always points to the centre of the primary. This effect is called tidal friction; it has already locked the moon so that it always presents virtually the same face to the earth, and is very slowly retarding the earth's speed of rotation on its axis.

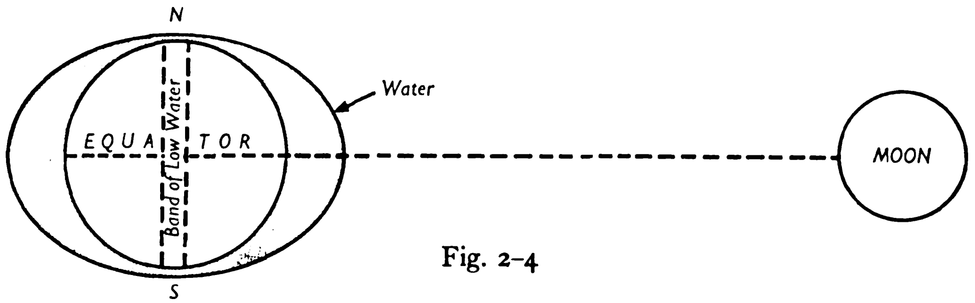

Fig. 2–4

Fig. 2–4 shows in exaggerated form a hypothetical earth completely covered with water, and an imaginary moon which remains stationary in relation to it on the celestial equator. There will be a permanent high water on the equator at points nearest to the moon and 180°* away, and a permanent band of low water joining the poles on the meridians 90° on either side. If the moon moves out to apogee, the positions of high and low water remain the same but the height of high water is not as high while the low water level is not as low. When the moon moves into perigee the reverse occurs and the high waters are higher while the low waters are lower. These minimum and maximum tides are known as apogean and perigean tides respectively.

Now let the earth start to rotate on its axis. The result will be high waters moving round the equator 180° apart with low waters 90° away from them. The tides nearer the poles will follow the same pattern, except that their ranges, i.e. the differences in height between low and high waters, will become less as the poles are approached; at the poles there will be no tide, only a permanent low water. Under these conditions there will be two high and two low waters during each rotation of the earth, or lunar day, and the tide is said to be semi-diurnal.

However, the position of high water will not now be at the point on the earth's surface nearest to the moon, since there will be a time lag due to the friction of the water moving over the earth's surface. As the moon moves out to apogee and back to perigee there will also be a lag in the effect that the tide producing forces have on the range of the tides, due to the inertia of the water.

b. Effect of changes in declination; the diurnal tide

Fig. 2–5 shows the moon in a fairly large declination of 20° North. High waters will be raised at the points *X* and *Y*, on the line joining the centre of the earth to the moon, and there will be a belt of low water along the great circle *AA′*, where the latitudes of *A* and *A′* are (90°—moon's declination).

Imagine that the earth is rotating once a day about the axis *NS*. At the point *A* (latitude 70° South) in the figure it is low water. At *B*, on a meridian 180° away it is high water. Therefore, in this latitude, and in all latitudes greater than the co-declination of the moon, there is only one high and one low water each day. The tide is said to be diurnal. At the poles there is no tide at all, but the permanent water level is higher than it is at *A* and *A′*.

At the point *C* in latitude 20° North there is a maximum high water, while at *D* in the same latitude and on the great circle *AA′* it is low water. At the point *E* in the same latitude and on a meridian 180° away from that through *C* it is again high water, but this time the high water is not as high as that at *C*. Since *D* is nearer to *E* than to *C*, it will take longer for the tide to fall than it does to rise. Along the parallel *FGH* the same pattern of unequal high tides and unequal intervals between high and low

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* The high water nearer the moon will in fact be a little higher than the one on the opposite side of the earth, since the moon's attractive force varies with distance. See section 11b of this chapter.

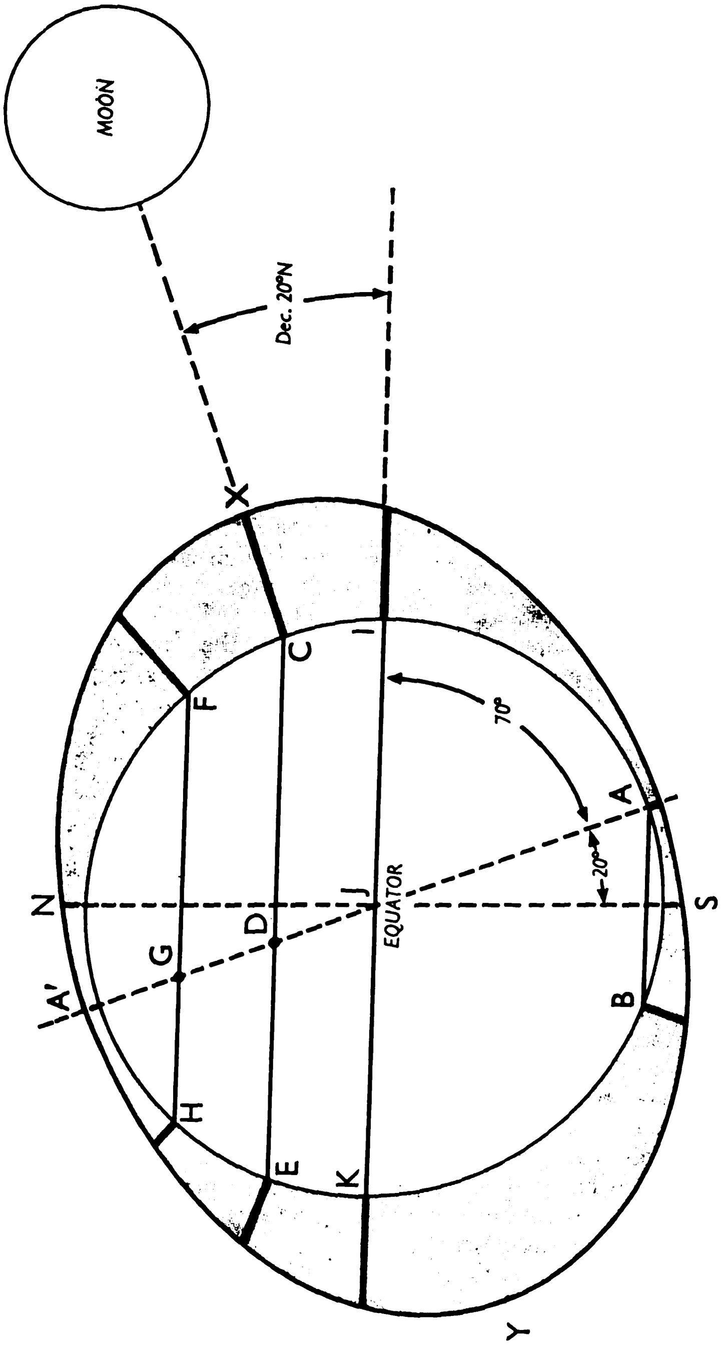

Fig. 2–5

water is followed; the range is less, but the inequality of time is greater. Due to their relationship with the diurnal tide, these inequalities of range and time interval are known as diurnal inequalities.

On the equator the semi-diurnal tide persists, for at *I* it is high water and at *J*, on a meridian 90° away, it is low water. At *K*, on a meridian 180° away from *I*, it is high water once again and the height is very nearly the same as that at *I*. The range of this tide is not as great as the range when the moon has a declination of 0°. The diurnal tide will always lag behind its tide producing force owing to friction and the inertia of water.

c. The combined effects of the sun and the moon

The sun has a tide producing effect on the earth similar to that of the moon, but the forces involved are not as great; its declination and the perihelion and aphelion effects act in the same way as the moon's declination, perigee and apogee.

The sun's tide producing forces sometimes act with and sometimes against those of the moon. At new and full moon the sun and moon act together, producing a tide raising force with a large range. Actual tides with big ranges usually occur a day or two afterwards. These tides are called spring tides, the name having nothing to do with the season of the year, and occur at approximately fortnightly intervals.

When the moon is at its first or last quarter, the height of the high water caused by its tide raising force at any place is partially counteracted by the low water effect caused by the sun at the same place. The result is a lower high water than at spring tides and a higher low water, that is the tide has a small range. Neap tides, as they are called, occur about a week after springs.

When spring tides coincide approximately with the time of the moon's perigee, perigean spring tides with extra large ranges are produced. Similarly when neap tides coincide approximately with the moon's apogee, apogean neap tides, with extra small ranges, occur.

The combined action of the sun and moon will increase the diurnal effect on tides when their declinations are both large, either in the same or opposite sense. The sun's declination cycle is completed once a year, while that of the moon takes about 27 days. The greatest diurnal effects occur when the moon is full at the solstices, in June and December.

d. The effect of land and shallow water

(i) Resonance; typical tidal curves. The theoretical explanation of diurnal tides does not always agree with observation, for there are places near the equator where the tides are definitely of a diurnal nature, and places in high latitudes where the tides have a semi-diurnal character. So far the world has been considered to be covered uniformly with water, and no consideration has been given to the effects of land and shallow water. The land divides the world's waters into oceans, seas and smaller bodies of water, and these upset the simple basic theory propounded above.

Each body of water has a natural period of oscillation, depending on its size and depth, which will have a great influence on its response to tide raising forces. The Pacific Ocean in general has a natural period of oscillation of about 25 hours. It is therefore resonant to the diurnal components of the tide producing forces; for this reason many of the tides in the Pacific are of a diurnal nature. There are a few places where, due to the configuration of the land and sea bottom, the natural period of oscillation of the particular basin is near that of the solar day of 24 hours. The water will therefore respond more to the solar tide producing forces than to those produced by the moon, notwithstanding the greater force exerted by the latter. The result will be a tide whose period is near that of the solar day, and high and low waters will occur at approximately the same time each day over a period of some weeks.

The natural period of oscillation of the Atlantic Ocean is about 12½ hours, so that it is generally resonant to the semi-diurnal tide producing forces. The result is that

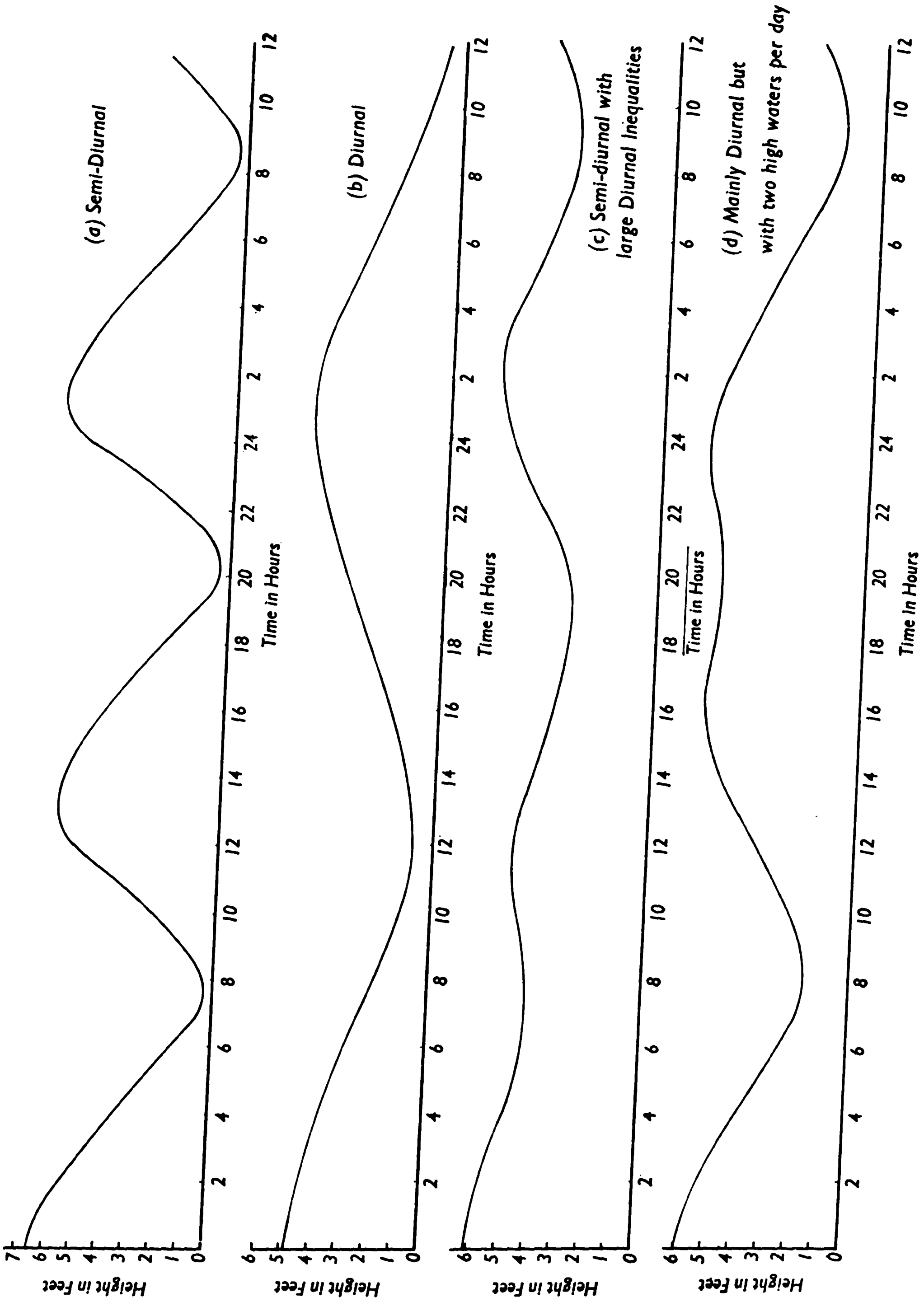
(a) Semi-Diurnal
(b) Diurnal
(c) Semi-diurnal with large Diurnal Inequalities
(d) Mainly Diurnal but with two high waters per day
Height in Feet
Time in Hours
0
1
2
3
4
5
6
7
2
4
6
8
10
12
14
16
18
20
22
24

Fig. 2–6

tides in the Atlantic are mainly semi-diurnal; however, there are exceptions caused by local conditions of resonance, notably near the north shore of the Gulf of Mexico, where the tides are mainly diurnal.

Fig. 2–6(a) shows a typical semi-diurnal tidal curve with two high waters and two low waters on each day. In this example there is a small amount of diurnal inequality which causes a variation in the heights of the high and low waters and in the time intervals between them. The typical diurnal tide in Fig. 2–6(b) has only one high and one low water in each day. Figs. 2–6(c) and (d) are examples of mixed tides with varying amounts of diurnal and semi-diurnal characteristics.

(ii) Determining the character of the tide. In the analysis and prediction of tidal movements mathematicians use different formulae, depending on whether the tide is 'mainly semi-diurnal' or 'mainly diurnal'. The surveyor, who often obtains the observations which will be analysed, must therefore know how to distinguish between these two types of tide.

In most cases he will be able to determine the character of the tide merely by studying the tidal curve, its mainly semi-diurnal or diurnal nature will be quite obvious. Where doubt exists, the following formulae have been devised to provide working criteria; they depend on the amplitudes of some of the harmonic constituents of the tide in question (see Section 10):

(*a*) If π (H of S_2) is greater than 2(H of K_1 + H of O_1) the tide is 'mainly semi-diurnal'.

(*b*) If π (H of S_2) is less than 2(H of K_1 + H of O_1) the tide has a relatively large diurnal component, and is 'mainly diurnal'.

In borderline cases the formulae for either type of tide may be used, and the results will be virtually the same.

In *Admiralty Tide Tables*, Part II, values for M.H.W.S. and M.L.W.S. are tabulated when the tide is semi-diurnal; for diurnal tides values for M.H.H.W., M.L.L.W., M.L.H.W. and M.H.L.W. are tabulated.

(iii) Non-tidal seas. The tide producing forces act over the whole world, and yet certain bodies of water such as the Eastern Mediterranean, Baltic, Caspian and Black Seas, are 'non-tidal'. These seas have natural periods of oscillation which make them relatively unresponsive to either the diurnal or semi-diurnal forces. Their natural periods of oscillation may vary from a few hours for a sea like the Mediterranean to a matter of minutes for an inland lake. The latter will therefore be virtually unaffected by oscillatory forces acting in periods of about 12 or 24 hours, while the former may respond faintly to the shorter period tide producing forces. Thus there are no measurable tides on the Round Pond at Kensington, but there is a slight response at the eastern end of the Mediterranean, with tides having a range of one or two feet.

(iv) Shallow water effects. When a wave travels into shallow water its shape is changed; this can be seen when waves run in on to a shelving beach. A wave produced by tide generating forces will be regular in shape in the open ocean and will have an amplitude of a foot or two. As it moves into shallow water, the wave crests will build up and the tidal range will increase. In this way the range in restricted, shelving waters like the Bristol Channel may build up to over 40 feet. The wave shape will also change so that the wave crests or high waters are accelerated and the troughs or low waters are retarded as the wave moves into shallower water, giving unequal periods between high and low water. Shallow water effects sometimes produce unusual anomalies, such as the double high water experienced at Southampton.

(v) Bores. When a tide with a large range is funnelled into a river or estuary with a steeply shelving bottom, a tidal bore may occur. This is an extreme case of the shallow water effects referred to above. It will usually occur at low water springs.

The tide rises rapidly and suddenly, producing a wall of water which moves up the channel over the rapidly shelving bottom. The wave front is steep and in some cases vertical; it may vary in height from one to about fifteen feet. This front advances up the river, usually against the last traces of the ebb stream, at a speed of anything from about three to twenty knots. It may or may not break. Behind it the water level continues to rise steeply, and half-tide level may be reached in less than an hour.

Bores are experienced in the Severn Estuary, the Solway Firth, the Hooghly River, and in many other places throughout the world.

4. Meteorological Effects; Surges and Seiches

a. Surges

Forces which have no connection with the astronomical tide producing forces can also produce wave forms similar to tides. They are usually of meteorological origin, but may sometimes be caused by earthquakes. The wave forms produced usually have shorter periods than tides, although there have been instances of very long periods, especially when the wave has been of seismic origin. These wave forms are known as surges. Large surges are sometimes erroneously referred to as 'tidal waves'.

The amplitude of a surge is small in the deep ocean, but it will build up as the wave moves into shallower water. This is exactly analogous to the build up of the tide described in Section **3d(iv)** above. The formation of surges is complicated and they are very difficult to predict. A surge will be superimposed on any tide that may be present and the two will build up together in shallow water. If the crest of a surge coincides with high water, a phenomenal high water will be produced, far above the predicted value, and disastrous floods may be experienced ashore; this was the case on the east coast of England and in the Thames Estuary in 1928 and 1953. More often, however, the two wave forms will be out of phase and the danger level will not be reached; sometimes the range may even be reduced. Whenever a surge is present an observed 'tidal curve' will differ from its predicted values.

A surge of meteorological origin is normally produced by conditions associated with depressions. A difference in barometric pressure between two places will result in a difference in water level; a fall of one inch of mercury (34 millibars) will cause the sea to rise about 13 inches. Due to the effects of inertia and friction the water level will not adjust itself immediately the barometric pressure alters. A steady, static pressure gradient will allow the sea surface to take up a state of equilibrium where over a large area there will be a small but measurable slope; but if a pressure gradient moves rapidly over an area, a state of equilibrium may never be reached, and a surge may be generated.

In addition to the effects of barometric pressure, the wind itself will pile up the water level, especially against a coastline. The two effects may combine to form a surge of considerable size, especially in the case of a fast moving depression. The progress and nature of a surge may be determined by taking simultaneous and continuous observations at several tide gauges along a stretch of coastline, and comparing the results with predicted heights. This is the method used by flood warning organisations.

b. Seiches

A surge generated in a restricted body of water, such as a long gulf or an inland sea, will have a short period in resonance with the natural period of the basin. The wave generated will probably be reflected backwards and forwards between facing coasts or reefs, especially if these are steep too; depending on the relationship between a basin's length, depth and breadth more than one wave form may be produced.

This type of reflected, short period surge is known as a seiche. Fig. 2–7 shows a tidal curve with a seiche imposed; in this case the period of the seiche is about half an hour while its amplitude is less than a foot. Measurable seiches with periods of the order of seconds occur in lakes.

A TYPICAL SEICHE

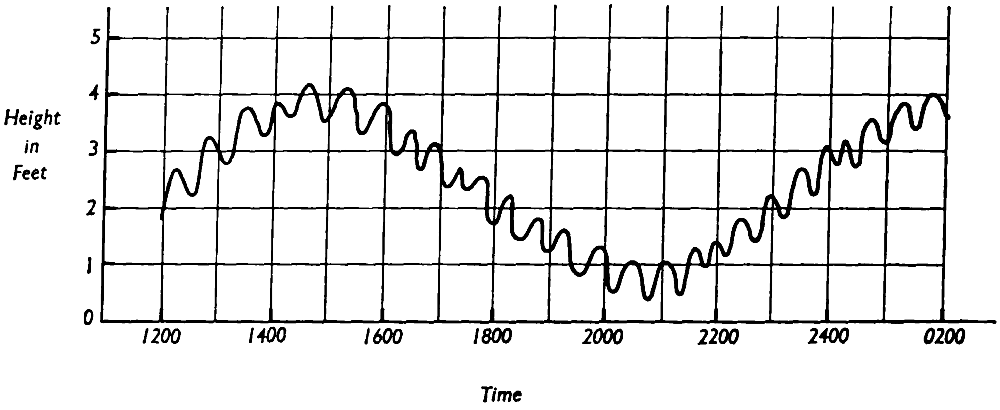

Fig. 2–7

5. Tidal Levels and Datums

When carrying out a survey, the surveyor must refer measured heights and depths to datum levels. These need not be the same provided the difference in level between them is known; indeed, for convenience they are normally different. A datum level may be chosen arbitrarily, but it should always be referred to a defined physical reference mark or bench mark; with this available, later surveyors will be able to connect their work to the original survey.

Datum levels chosen for a published chart should be convenient and logical. For this reason they are usually connected by levelling to a tidepole, and therefore to any convenient level of the sea. Not all datums are based on a value of 'sea level' but, as stated above, they must all be connected to a master bench mark which is a permanent, visible indication of level. The master benchmark will normally be connected to a system of benchmarks covering the whole country with a rigorous network. By using any of these benchmarks the surveyor may refer all the heights and depths in his survey to a national datum or, if more convenient, to his own datums which will have known values relative to the national datum.

Some of the more important water levels and datums are described below.

a. Mean Sea Level

As its name implies, Mean Sea Level (M.S.L.) is the average level taken up by the sea. It coincides very nearly with the geoid (see Volume 1, Chapter 2). Although this sounds very simple, it is not easy to obtain an accurate value for Mean Sea Level, since the actual level of the sea is continually altering. Changes in level may be caused by anything from very short term fluctuations, e.g. sea and swell, to very long term movements, which may take decades or even centuries to become appreciable. In addition to the fairly regular, predictable changes due to tide, there are irregular and spasmodic fluctuations caused by surges and seiches, which are generally quite unpredictable. The cause of a sudden change in level may not always be immediately apparent. For instance, a storm at one end of the Baltic Sea may cause a sudden change in water level at the other end, even though conditions there are calm and free from the effects of wind; the water may be maintained at the new level for some days before it reverts to normal.

Seasonal changes in Mean Sea Level occur when winds blow regularly in the same direction over definite periods of a year (e.g. monsoons), or where large amounts of fresh water are released after heavy seasonal rains, or when ice melts. The average seasonal changes in Mean Sea Level at secondary ports are given in *Admiralty Tide Tables, Part II*; it would be reasonable to interpolate values for intermediate places.

The reliability of a value for Mean Sea Level will depend on the length of the period of observation taken to determine it. A value of sorts may be determined by meaning 25 hourly observations; a more reliable result will be obtained from 39 hourly observations treated in the manner described in *Admiralty Tidal Handbook No. 2*, para. 35. Better still will be the result obtained by meaning hourly heights of water level observed over a period of 29 days. The best results cannot be obtained from observations which do not extend over a period of at least 18·6 years (one cycle of the moon's nodes). Note that the value of Mean Sea Level is automatically obtained when carrying out a harmonic analysis of tidal observations by the methods described in *Admiralty Tidal Handbooks Nos. 1* and *3*. In non-tidal waters a long period of observation is no less important.

b. Mean Tide Level

Mean Sea Level must not be confused with Mean Tide Level (M.T.L.), which is the average value of all the heights of high and low waters over a period. The two values will only agree if the tidal curve is perfectly symmetrical. Mean Tide Level may be obtained in the field more easily than Mean Sea Level, and from fewer observations. For this reason it is sometimes used in calculations instead of M.S.L. Either term is replaced at times by the expression Mean Level (M.L.).

c. Mean High and Low Water Springs

The height of Mean High Water Springs (M.H.W.S.) is the average, throughout a year when the average maximum declination of the moon is 23½°, of the heights of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is greatest. The height of Mean Low Water Springs (M.L.W.S.) is the average height obtained by the two successive low waters during the same periods. Values of M.H.W.S. and M.L.W.S. vary slightly from year to year in a cycle of 18·6 years (the cycle of the moon's nodes); they will also vary with changes in Mean Sea Level.

d. Mean High and Low Water Neaps

The height of Mean High Water Neaps (M.H.W.N.) is the average, throughout a year as defined in **c** above, of the heights of two successive high waters during these periods (approximately once a fortnight) when the range of the tide is least. The height of Mean Low Water Neaps (M.L.W.N.) is the average height obtained from the two successive low waters during the same periods. Values of both will vary slightly from year to year in a cycle of 18·6 years, and with changes in Mean Sea Level.

e. Mean Higher High Water and Mean Lower Low Water

When tides are mainly diurnal in character the values of Mean Higher High Water (M.H.H.W.) and Mean Lower Low Water (M.L.L.W.) are normally referred to instead of M.H.W.S. and M.L.W.S. Mean Higher High Water is the mean of the higher of the two daily high waters experienced over a period; when only one high water occurs on a day, this is taken as the higher high water. Mean Lower Low Water is the mean of the lower of the two daily low waters experienced over a period of time.

These values are used in non-harmonic tidal predictions using tide tables (see *Admiralty Tide Tables, Part 2*) where the tides are mainly diurnal. In this method of prediction the mean values of the heights of lower high water (M.L.H.W.) and higher low waters (M.H.L.W.) will also be required.

f. Chart datum; Lowest Astronomical Tide

Chart datum is the level to which soundings on a published chart are reduced, and above which tidal predictions and tidal levels are given in the tide tables. In theory it should be chosen so that:

(1) The tide never falls below it. The mariner may therefore be confident that under normal weather conditions there will be at least as much water as is shown on the chart.

(2) It is not so low as to give unduly shallow depths; therefore, its level should not be below that of the lowest tides experienced.

(3) Soundings will be in close agreement where areas having different datums adjoin, i.e. chart datum must not be altered by too much in one step.

Mean Low Water Springs and various other levels have been used for chart datum in the past, but for modern Admiralty charts the aim is to use a level known as the Lowest Astronomical Tide (L.A.T.). By definition the Lowest Astronomical Tide is the lowest level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions. There is no simple formula or rule available to calculate it from observations or tidal constituents. It can only be obtained properly by studying tidal predictions covering several (ideally about 18) years, as the level of L.A.T. will not be reached every year. Even when a level is obtained in this manner, it may contain small errors if the predictions are based on very old observations or observations taken over a relatively short period (less than a year), or during abnormal meteorological conditions.

Since L.A.T. is so difficult to obtain, chart datum for Admiralty charts has been rather more broadly defined as the level below which no predicted tide shall fall by more than 0·3 feet.

Fig. 2–8 shows a typical relationship between some of the levels described in **a** to **d** above and chart datum; a suitable level for chart datum would be anywhere between the levels marked 'Chart Datum' and 'L.A.T.'. It should be noted that the water may fall below the level of L.A.T. if abnormal meterological conditions are experienced.

In non-tidal waters chart datum is usually established at Mean Sea Level.

g. Sounding datum

Sounding datum is the level to which soundings are reduced in the course of a hydrographic survey, and is therefore the datum used for the completed fair chart or final tracing. Ideally sounding datum should be the same as chart datum; however the two may well differ, particularly in original surveys. It is quite possible to choose sounding datum after only a day's tidal observations, and to obtain chart datum much later, after analysing a series of tidal observations which may cover a month or more.

Admiralty Tidal Handbook No. 2 should be consulted for methods of obtaining a sounding datum. Section 6 below gives sufficient information to enable the surveyor to obtain a satisfactory sounding datum for a minor or sketch survey, or for any survey where a more suitable chart datum will be obtained later from a series of tidal observations.

h. Indian Spring Low Water

Indian Spring Low Water is a level for chart datum suggested by Sir George Darwin for Indian waters. It is found by obtaining the sum of the semi-ranges of the principal lunar and solar semi-diurnal tides, and of the lunar and luni-solar diurnal tides, and subtracting it from Mean Sea Level. It is given by the formula:

$$\text{Indian Spring Low Water} = Z_0 - (M_2 + S_2 + K_1 + O_1)$$

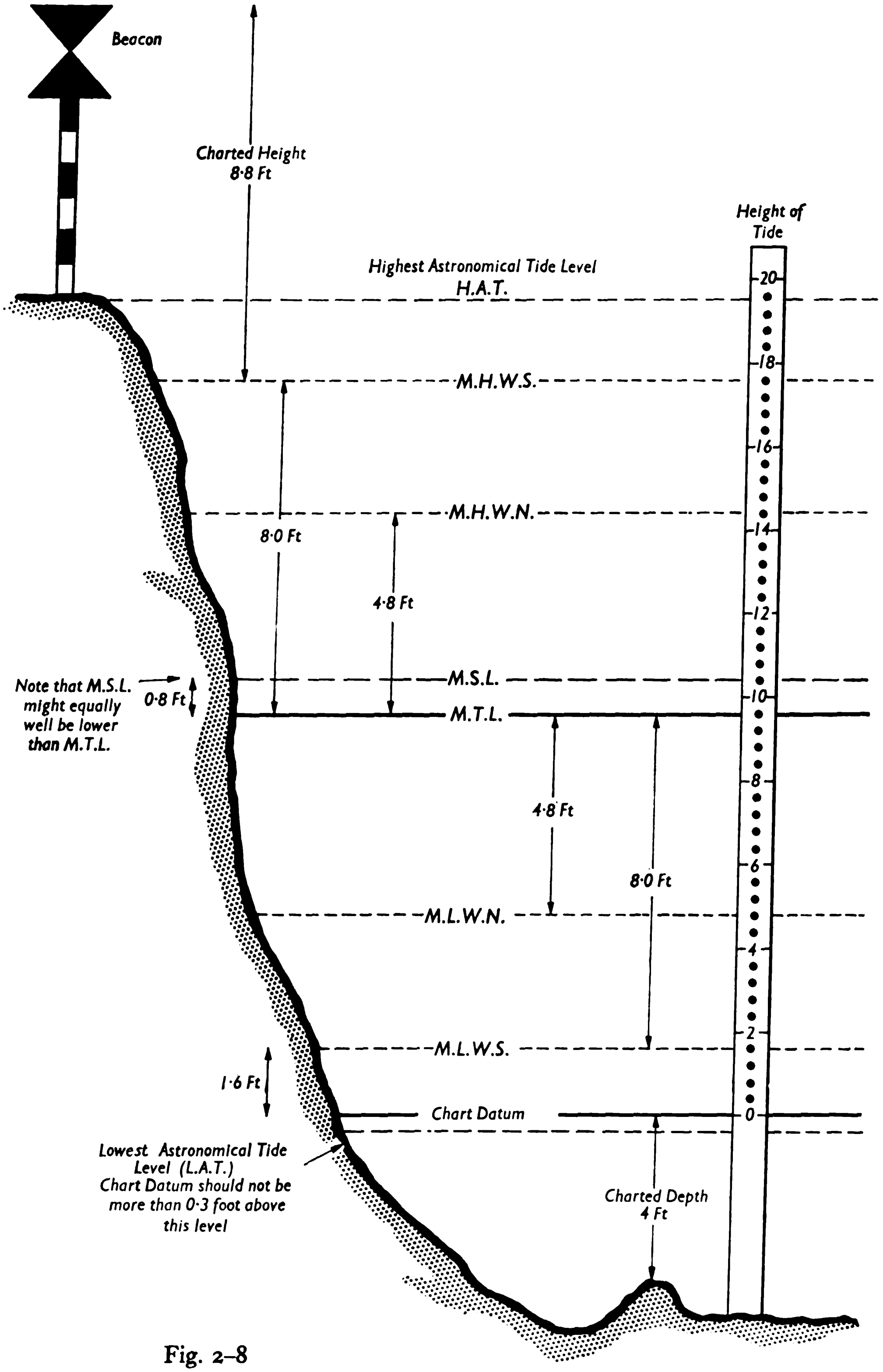
Beacon
Charted Height
8·8 Ft
Height of
Tide
Highest Astronomical Tide Level
H.A.T.
20
18
16
14
12
10
8
6
4
2
0
M.H.W.S.
M.H.W.N.
8·0 Ft
4·8 Ft
M.S.L.
Note that M.S.L. might equally well be lower than M.T.L.
0·8 Ft
M.T.L.
4·8 Ft
8·0 Ft
M.L.W.N.
M.L.W.S.
1·6 Ft
Chart Datum
Lowest Astronomical Tide Level (L.A.T.)
Chart Datum should not be more than 0·3 foot above this level
Charted Depth
4 Ft

Fig. 2–8

where Z_0 is Mean Sea Level, and M_2, S_2, K_1, and O_1 are the amplitudes* of the principal semi-diurnal and diurnal tidal constituents, which are described in Section 10 of this chapter.

Indian Spring Low Water has been found to be suitable for chart datum in certain parts of the world, notably in the south-west part of the Persian Gulf and certain parts of India, Malaysia and Borneo.

6. Obtaining a Sounding Datum

a. Basic rules

When establishing sounding datum the surveyor should bear the following points in mind:

(1) If possible sounding datum should agree with chart datum. If the finding of chart datum is likely to take a long time because of the tidal observations required, the commencement of sounding should not be delayed on this account. A sounding datum should be obtained, fairly arbitrarily if necessary, from the tidal observations available by the end of the first day's sounding.

(2) Changes in sounding datum within the area must be made whenever the nature and the range of the tide alter appreciably. This is very important. It is difficult to lay down precise figures, but a difference in range of about two feet between two places would normally indicate the necessity for a change of datum somewhere between them.

(3) The time difference between the tides experienced at two places will not have any effect on the difference of sounding datum between them. It may however have a considerable effect on the value of the reduction required to reduce soundings to datum; time differences will have a maximum effect on reductions when the tidal level is altering most rapidly; this will usually be at half tide. It is therefore important, even though sounding datum does not alter, to obtain time differences between tidal stations, so that a time difference may be interpolated and applied to tidal observations used for the reduction of soundings in an area some distance from a tide gauge.

(4) If there is any doubt at all in the surveyor's mind concerning the behaviour of the tides, he should set up another tide pole to find out what is happening.

b. How sounding datum changes on an open coast

Fig. 2-9 shows how the levels of M.L.W.S. and M.H.W.S. might alter in relation to a fixed land datum along an imaginary coastline 50 miles long. It can be seen that at 0 miles the tidal range is about 6½ feet and the level of M.L.W.S. is four feet below the fixed datum, while at 50 miles the range has increased to 24 feet and the level of M.L.W.S. is 13 feet below the fixed datum. It will obviously be quite unsuitable to select a fixed sounding datum covering the whole area. In theory sounding datum should alter at the same rate as the level of M.L.W.S., as indicated by the pecked line in the figure. However, this would make it necessary to calculate the reduction for each sounding separately. In practice it will be prudent to alter sounding datum in a series of steps about one foot high so that it follows the curve of the ideal datum. Typical steps which would be very suitable are shown in the diagram.

c. How sounding datum changes in an estuary or river

Tidal conditions will alter rapidly where the configuration of the land and the slope of the sea-bed cause the tidal range to build up; this situation may be expected in an

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* Note that for tidal work 'amplitude' is equal to half the range of the tide; thus the amplitude of the tide is its greatest height above or below mean level.

TIDAL LEVELS ON AN OPEN COAST

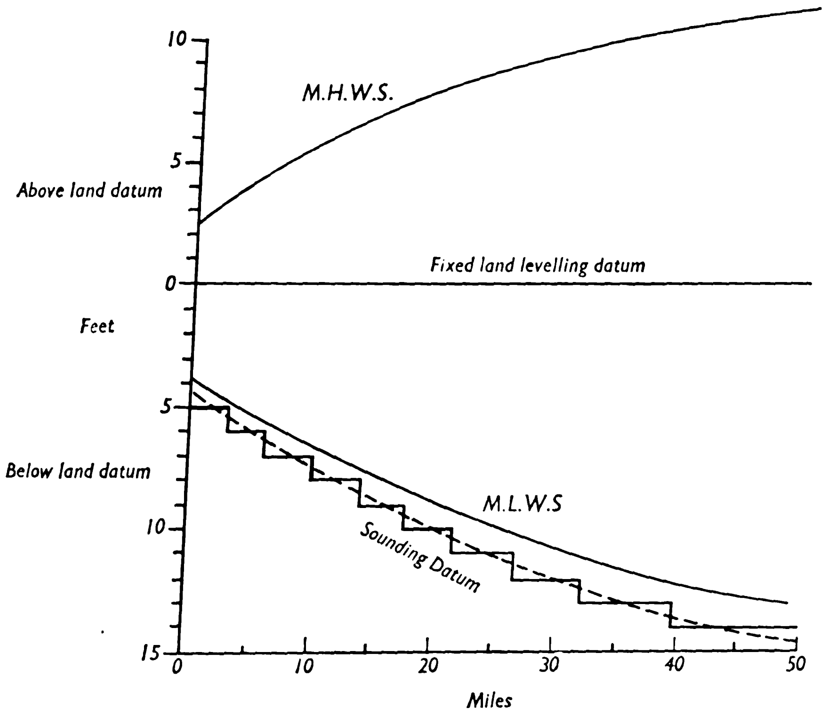

Fig. 2–9

estuary or up a river. When proceeding up a river, the surveyor will notice from his tidal observations that at first the range increases, high waters becoming higher and low waters falling lower. This continues until a point is reached where the topography of the river bed prevents the low waters from falling any lower. Upstream from this point the surveyor will notice that the heights of low water increase; at spring tides they will increase faster than at neaps. The point may be reached where the level of M.L.W.N. coincides with or even falls below the level of M.L.W.S. Fig. 2–10 illustrates variations in tidal levels and established chart datum in a typical river and its estuary; it will be noticed that chart datum is lowest at about the point where the level of M.L.W.S. also reaches its lowest level.

d. Sounding datums for an original survey covering a large area

It is not easy to establish suitable sounding datums for a hydrographic survey which covers a long stretch of coastline where the tidal conditions are unknown. Tidal information in the area must be built up as the survey progresses, and sounding datum transferred gradually along the coast. This may be done in the following way:

(1) Set up a tide gauge within about five miles of the edge of the survey area where work is to start.

(2) Obtain sufficient tidal observations at this gauge to enable a sounding datum to be established. In order to obtain a value of chart datum for the final published chart, observations should be taken for at least 29 days; it may be convenient to carry out this work with a small advance party. If, however, it is impossible to do this before sounding is due to commence, then a sounding datum should be

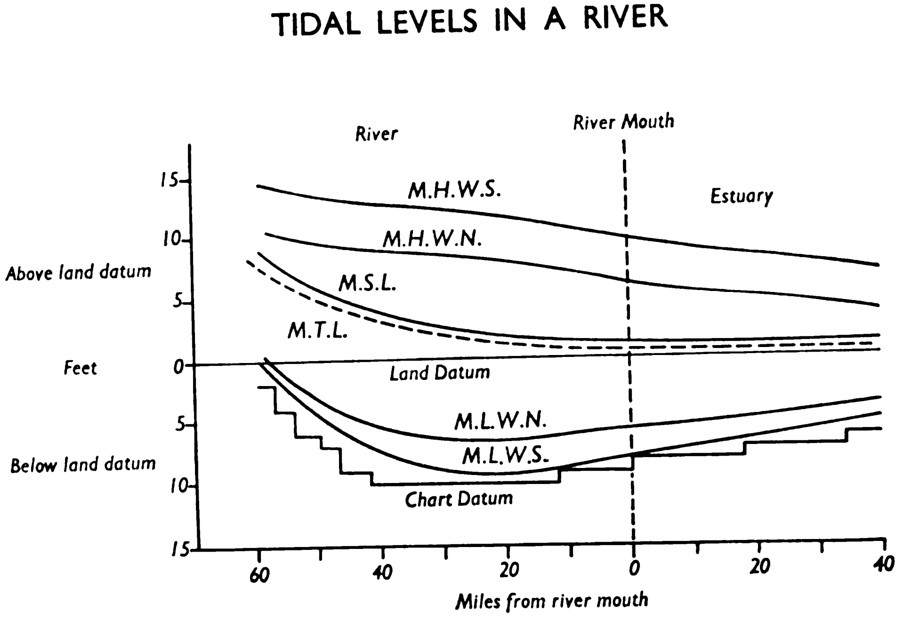

Fig. 2–10

established from whatever observations are available. If these extend over a period of less than 25 hours, it may be obtained by the method described in **h** below; it will be of no great importance if it differs slightly from the final chart datum.

(3) At the earliest opportunity set up another tide gauge about 10 miles up the coast, and transfer datum to it from the first gauge by the appropriate method described in **g** below.

(4) If the heights between the sounding datums and 'observed mean levels' at the two gauges differ from each other by much more than a foot, or if the two tidal curves are very different in shape, or the time differences are large,* set up an intermediate gauge (or gauges if necessary) and transfer datum to it.

(5) As the survey progresses continue setting up tide gauges well ahead of the sounding, the distances between adjacent sites being chosen so that the rules set out in (4) above are not broken.

e. Methods of obtaining sounding datum

The surveyor can obtain sounding datum by one of the following means, which are given in order of preference:

(1) Where chart datum is already established in the survey area, he should recover it and use it as sounding datum. See **f** below.

(2) Where chart datum is already established at a place near the survey area, he should transfer datum to the survey area. See **g** below.

(3) Where no chart datum has been established in or near the survey area, the surveyor must establish his own sounding datum. This he may do by the method described in **h** below. If the necessary observations are available before sounding starts, he will probably obtain a sounding datum nearer to the final value of chart

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* It is impossible to define a 'large' time difference, since the range of the tide is always involved. Thus with a 40-foot range 10 minutes might well be a large time difference; it would certainly not be large if the range were only three feet.

datum if he uses the appropriate method described in *Admiralty Tidal Handbook No. 2.*

f. Recovering an established datum; interpolating datum

If chart datum is already established in an area it may be described on the largest scale Admiralty chart; it will always be obtainable from the Tidal Branch of the Hydrographic Office. Normally the datum will be referred to a local land levelling system and a local benchmark (or benchmarks). The surveyor must find the benchmark concerned and connect it by levelling to the tide gauge which is to be used for the reduction of soundings (see Volume 1, Chapter 9, Section **8**).

Where chart datum has been established at fairly close intervals, sounding datum may be interpolated. This is often possible in the British Isles.

For example, suppose that sounding datum is required at Happisburgh with chart datum established at Winterton and Cromer (see Fig. 2–11). From the largest scale Admiralty chart (or in the British Isles from Table VI of *Admiralty Tide Tables Vol. I*) chart datum has been established as follows:

Chart datum at Winterton: 5·40 feet below Ordnance datum (Newlyn)
Chart datum at Cromer: 7·82 feet below Ordnance datum (Newlyn)

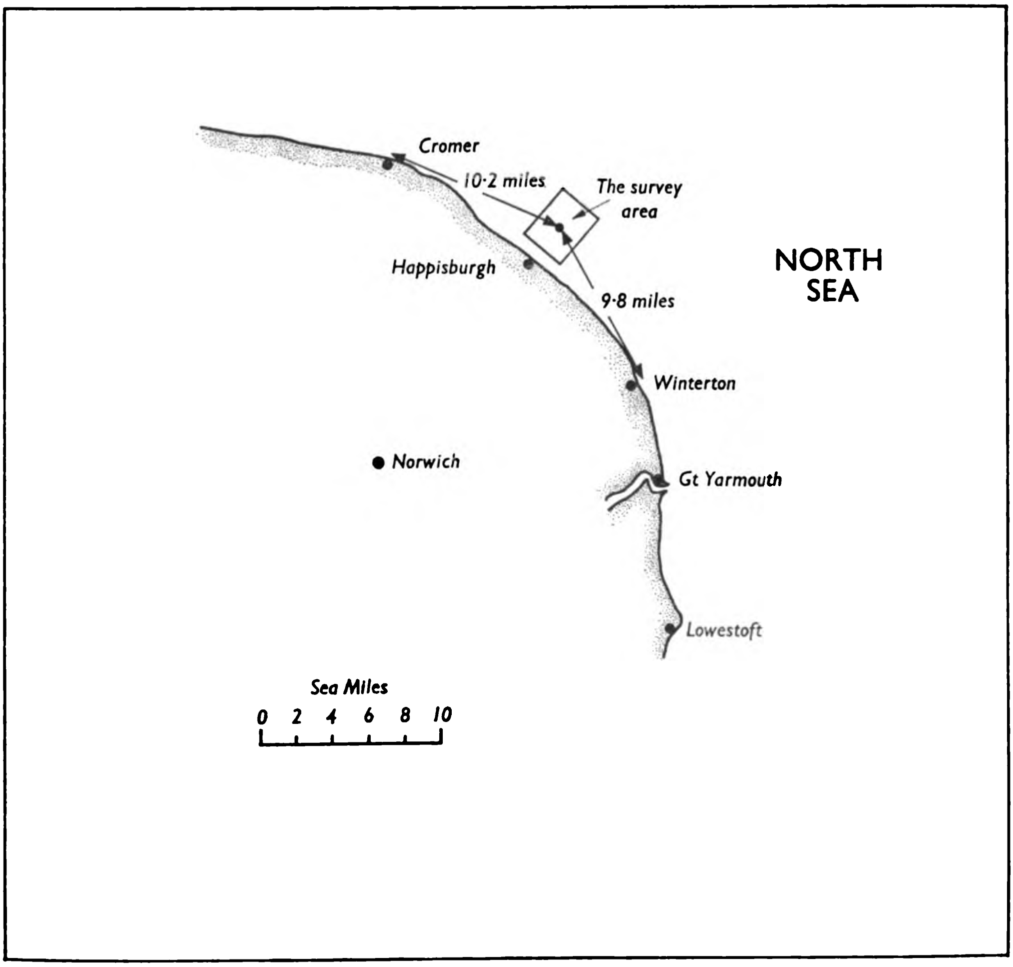

Fig. 2–11

Then, by interpolation, a suitable sounding datum for the survey area off Happisburgh would be

$$5{\cdot}40 + \left[(7{\cdot}82 - 5{\cdot}40) \times \frac{9{\cdot}8}{(9{\cdot}8 + 10{\cdot}2)}\right]$$

$$= 6{\cdot}59 \text{ feet below Ordnance datum.}$$

If a suitable Ordnance Survey benchmark exists near the tide gauge at Happisburgh, sounding datum can be established easily and accurately by levelling.

g. Transferring a datum

If chart datum has been established near the survey area, it may be transferred to the survey area by taking simultaneous tidal observations over a period. To do this the surveyor must set up tide gauges at the place where chart datum is established and in the survey area. He must then obtain the value of chart datum on the tide gauge at the place where it is established, by levelling. The tidal observations required for transfer and the methods used to obtain the transferred datum will differ depending on whether the tide is mainly semi-diurnal or has a relatively large diurnal component (see Section **3d(ii)**). They are described below:

(i) Transferring a datum when the tide is semi-diurnal. Simultaneous observations are required at both places to give heights of four consecutive low waters and three intermediate high waters at or near springs.* When transferring datum up a river it will be advisable to carry out the observations at neaps as well as springs, and to use the lower value for the transferred datum (see Section **6c** above).

The procedure for calculating datum at the new gauge is as follows:

(1) Plot the tidal observations at each gauge on squared paper. From the curves obtain the heights of the low and high waters. At the established gauge these should be referred to chart datum.

(2) Calculate 'Observed Mean Low Water' and 'Observed Mean High Water' at each gauge. In order to minimise the effects of diurnal inequality these should be calculated as follows:

$$\text{Observed M.L.W.} = \frac{(a + 3c + 3e + g)}{8}$$

$$\text{Observed M.H.W.} = \frac{(b + 2d + f)}{4}$$

where a, c, e and g are the observed heights of the four consecutive low waters, and b, d and f are the observed heights of the three consecutive high waters.

(3) Calculate 'Observed Mean Range' at each gauge from the differences of 'observed M.L.W.' and 'observed M.H.W.'.

(4) Calculate 'observed Mean Tide Level' at each gauge from the means of the 'observed M.L.W.s' and 'observed M.H.W.s'. This level is often referred to as 'Mean Level'. Provided the two tidal curves are very similar in shape, which they must be to carry out an accurate transfer, it is immaterial whether Mean Sea Level or Mean Tide Level is used, so long as it is the same at both gauges. Mean Tide Level is generally used to save effort, but where full sets of tidal observations are available the use of 'observed M.S.L.' will probably give a better result. (See Section **5a** above.)

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* The main reason why spring tides are chosen is that their ranges will be large compared with unwanted variations caused by meteorological phenomena. In the absence of all errors of observation and outside influences observations at springs or neaps would produce the same answer.

(5) If the values of M.H.W.S. and M.L.W.S. above chart datum at the established gauge are given in *Admiralty Tide Tables Part II* (or *Table 5* for Standard Ports), calculate M, the 'true Mean (Tide) Level at Springs':

$$M = \tfrac{1}{2}(\text{M.H.W.S.} + \text{M.L.W.S.}).$$

(6) If step (5) was taken, calculate sounding datum at the new gauge from the following formula:

$$d = m' - (M' - M) - \frac{Mr}{R}$$

where d is the height of sounding datum above zero of the new gauge;

m′ is the height of observed mean (tide) level above the zero of the new gauge;

M′ is the height of observed mean (tide) level above chart datum at the established gauge;

M is the height of 'true Mean (Tide) Level at Springs' above chart datum at the established gauge;

r is the observed mean range at the new gauge;

and R is the observed mean range at the established gauge.

If step (5) cannot be taken, the following formula, in which the symbols are the same, should be used:

$$d = m' - \frac{M'r.}{R}$$

There will not be a great deal of difference in the final result, whichever formula is used, but the first is better when the values of M.H.W.S. and M.L.W.S. above chart datum at the established gauge are known, since these will have been obtained from a long period of observations.

The calculation may be carried out as follows:

TRANSFERRING DATUM: SEMI-DIURNAL TIDES

	ESTABLISHED GAUGE Heights above chart datum					NEW GAUGE Heights above the zero				
	H.W.	*L.W.*	*Factor*	*H.W.*	*L.W.*	*H.W.*	*L.W.*	*Factor*	*H.W.*	*L.W.*
a	—	2·5	×1	—	2·5	—	6·3	×1	—	6·3
b	21·0	—	×1	21·0	—	20·8	—	×1	20·8	—
c	—	3·5	×3	—	10·5	—	7·5	×3	—	22·5
d	20·2	—	×2	40·4	—	20·3	—	×2	40·6	—
e	—	2·3	×3	—	6·9	—	6·2	×3	—	18·6
f	21·3	—	×1	21·3	—	21·0	—	×1	21·0	—
g	—	3·2	×1	—	3·2	—	7·1	×1	—	7·1
Sum				82·7	23·1			....	82·4	54·5
Mean H.W. $= \frac{\text{Sum}}{4}$, Mean L.W. $= \frac{\text{Sum}}{8}$				20·7	2·9			....	20·6	6·8
Range = H.W. − L.W.				R = 17·8				....	r = 13·8	
Observed Mean (Tide) Level $= \frac{\text{H.W.} + \text{L.W.}}{2}$ $= M' = 11{\cdot}8$								....	m′ = 13·7	

(*a*) Where M.H.W.S. and M.L.W.S. at the established gauge are known:

$$\begin{aligned} \text{M.H.W.S.} &= 20{\cdot}0 \\ \text{M.L.W.S.} &= 1{\cdot}0 \\ \tfrac{1}{2}\text{ Sum} = \text{M} &= 10{\cdot}5 \end{aligned}$$

and

$$\begin{aligned} \text{d} &= \text{m}' - (\text{M}' - \text{M}) - \frac{\text{Mr}}{\text{R}} \\ &= 13{\cdot}7 - (11{\cdot}8 - 10{\cdot}5) - \frac{10{\cdot}5 \times 13{\cdot}8}{17{\cdot}8} \\ &= 13{\cdot}7 - 1{\cdot}3 - 8{\cdot}1 = 4{\cdot}3 \text{ feet.} \end{aligned}$$

Therefore sounding datum on the new gauge is 4·3 feet above the zero.

(*b*) Where 'true Mean (Tide) Level at Springs' at the established pole is not known:

$$\begin{aligned} \text{d} &= \text{m}' - \frac{\text{M}'\text{r}}{\text{R}} \\ &= 13{\cdot}7 - \frac{11{\cdot}8 \times 13{\cdot}8}{17{\cdot}8} \\ &= 13{\cdot}7 - 9{\cdot}1 \\ &= 4{\cdot}6 \text{ feet.} \end{aligned}$$

Therefore, in this case, sounding datum on the new gauge is 4·6 feet above the zero.

(ii) Transferring a datum when the tide is diurnal. In order to transfer datum when the tide is diurnal, it is necessary to obtain the main harmonic constituents for the tide at each gauge by analysing simultaneous observations (see Section **10**). For the best results observations should be carried out for a period of 29 days and analysed in accordance with *Admiralty Tidal Handbook No. 1.* If this is not possible, then two or more series of 25 hourly observations, preferably taken when the range is large, should be made simultaneously at both poles and analysed by the method shown in *Admiralty Tidal Handbook No. 3.*

From the results of the analysis, chart (or sounding) datum at the new gauge may be obtained from the formula:

$$\text{d} = \text{z}' + (\text{Z}_0 - \text{Z}') - \text{Z}_0 \times \frac{\text{h}}{\text{H}}$$

where d is the height of chart datum above zero of new gauge;

Z′ is the height, above chart datum, of M.S.L. at the established gauge (this is given as Z_0 on the analysis form);

z′ is the height of M.S.L. above the zero of the new gauge (this is given as S_0 on the analysis form);

Z_0 is the 'true' height of M.S.L. above chart datum at the established gauge (obtained from *Admiralty Tide Tables Part II*);

H is the sum of the amplitudes (H on the analysis form) of the four principal constituents ($M_2 + S_2 + K_1 + O_1$) obtained from the analysis of the observations at the established gauge;

and h is the sum of the amplitudes of the same constituents at the new gauge.

If the value of Z_0 is not available from *Part II* of the appropriate volume of *Admiralty Tide Tables*, then the following formula should be used:

$$\text{d} = \text{z}' - \left(\text{Z}' \times \frac{\text{h}}{\text{H}}\right)$$

For example, suppose that it is required to transfer datum from Miri in Sarawak, Borneo, a Standard Port where chart datum is established, to Kuala Bintulu some distance to the south. From two sets of simultaneous observations of 25 hourly observations taken at each place when the range was large, the tidal constituents at each place were obtained by analyses carried out by the method described in *Admiralty Tidal Handbook No. 3*, and are as follows:

At MIRI:	H of M_2 = 0·45	At BINTULU:	H of M_2 = 0·50
	H of S_2 = 0·20		H of S_2 = 0·15
	H of K_1 = 1·30		H of K_1 = 1·55
	H of O_1 = 1·05		H of O_1 = 1·20
	Sum = H 3·00		Sum = h 3·40
Z′ (Z_0 on the analysis form)	= 3·25	z′ (S_0 on the analysis form)	= 4·10
Z_0 (from *Admiralty Tide Tables, Vol. III Part 2*)	= 3·5		

(*a*) Where Z_0 is known from *Admiralty Tide Tables*:

$$d = z' + (Z_0 - Z') - Z_0 \times \frac{h}{H}$$

$$= 4{\cdot}10 + 0{\cdot}25 - 3{\cdot}5 \times \frac{3{\cdot}40}{3{\cdot}00} = 0{\cdot}35.$$

Therefore chart datum is 0·35 feet above the zero of the new gauge.

(*b*) Where Z_0 is not tabulated in *Admiralty Tide Tables*:

$$d = z' - Z' \times \frac{h}{H}$$

$$= 4{\cdot}10 - 3{\cdot}25 \times \frac{3{\cdot}40}{3{\cdot}00} = 4{\cdot}10 - 3{\cdot}68 = 0{\cdot}42.$$

Therefore chart datum is 0·4 feet above the zero of the new gauge.

As in the case of the two formulae used with semi-diurnal tides, the discrepancy between the two results is due to the fact that the value of M.S.L. at the established gauge is obtained from a considerably longer period of observations in the first formula than in the second; for this reason the first formula should always be used if possible.

If *Admiralty Tidal Handbooks Nos. 1* or *3* are not available, and the harmonic constants are not known, sounding datum can always be established by the method described in **h** below. The observations referred to above should always be obtained if possible, so that an analysis can be made later.

h. Establishing sounding datum from a few hours observations

Provided the period of observation covers at least one high water and an adjacent low water, a reasonable sounding datum may be obtained by reference to the predicted tides at the nearest or appropriate standard port. The nearest standard port may not always be the correct one to refer to, since the nature of the tides there may differ considerably from those in the survey area. Inspection of *Part II* of the appropriate volume of *Admiralty Tide Tables* should indicate the correct standard port; it will be that to which the nearest secondary ports on either side of the survey are referred.

Having obtained his observations, the surveyor should proceed as follows:

(1) Find the observed range of the day at the tide gauge in the survey area.

(2) Find the Mean Tide Level at the tide gauge by meaning the heights of high and low water.

(3) From *Admiralty Tide Tables* obtain the predicted range of the day at the standard port. If there is doubt concerning the appropriate tidal cycle to use, when the tidal cycles at the standard port and the survey area are out of phase by about half a cycle, it may be resolved by reference to the time differences given in *Admiralty Tide Tables Part II* for the secondary ports on either side of the survey area.

(4) Obtain the ratio: $\frac{\text{Observed range at the tide gauge}}{\text{Predicted range at the standard port}}$

(5) Study the predicted tides at the standard port in *Admiralty Tide Tables* and select any day when the tide is predicted to fall to, or very nearly to, datum (i.e. when the predicted height of a L.W. is nearest to zero).

(6) Extract the predicted range at the standard port for that day and apply the ratio obtained in (4) to it to obtain the equivalent range at the tide gauge.

(7) Sounding datum is then obtained by subtracting half the equivalent range in (6) from the observed M.T.L. on the gauge calculated in (2).

For example, suppose that a datum is required quickly for a survey off Ras Sukra in Southern Arabia. This place is situated between Jazirat Hallaniya (Kuria Muria Islands) and Ras Madraka, which are shown in *Admiralty Tide Tables, Vol. II, Part II,* as being secondary ports based on the standard port of Karachi. A tide pole is set up at Ras Sukra and a day's observations produce the following results:

Observed high water	7·8 feet
Observed low water	2·1 feet

Therefore observed range = 5·7 feet

and observed M.T.L. = 4·95 feet

From *Admiralty Tide Tables, Vol. II, Part I,* the predicted heights at Karachi, the standard port, are:

High water	9·6 feet
Low water	3·6 feet

Therefore range = 6·0 feet

$$\text{And the ratio of ranges} = \frac{5{\cdot}7}{6{\cdot}0} = 0{\cdot}95.$$

In *Admiralty Tide Tables, Vol. II, Part I,* the tide at Karachi is predicted to rise to a maximum height of 9·7 feet on a day when it falls to datum. Therefore the range on that day is 9·7 feet.

Applying the ratio of ranges, the equivalent range at the tide pole becomes:

$$9{\cdot}7 \times 0{\cdot}95 = 9{\cdot}2 \text{ feet,}$$

and the equivalent half range = 4·6 feet.

Sounding datum on the tide pole at Ras Sukra therefore is:

Observed M.T.L. – equivalent half (maximum) range

$$= 4{\cdot}95 - 4{\cdot}6 = 0{\cdot}35 \text{ feet above zero.}$$

(i) Checking the suitability of sounding datum. If, after sounding datum has been established by the method described in **h** above, sufficient tidal observations are taken to enable a harmonic analysis by the methods described in either *Admiralty*

Tidal Handbook No. 1 or *3* to be made, then the suitability of the datum should be checked as follows:

(1) Find from *Admiralty Tide Tables Part I* the day on which the tide is predicted to fall to its lowest level at the standard port.

(2) Using the harmonic constants obtained from the analysis, compute the tidal curve for that day in the survey area either on form *HD 289* or on a portable predicting machine. Form *HD 289*, supplied in book form, is quite simple to use and contains full instructions.

(3) If the chosen sounding datum is correct, the low water level obtained from (2) should fall to the same height relative to sounding datum as the predicted L.W. at the standard port relative to chart datum.

7. Datums in Offshore Waters; Co-Tidal Charts

a. The reduction of soundings in offshore waters

The method used for reducing soundings in offshore waters will depend on the accuracy required and the equipment available to the surveyor. Chapter 3, Section 29, of this volume gives the normal methods used for reducing soundings in a coastal survey from tide gauge readings, and Section **9d** below contains additional information.

Where the reduced depth of water is over 20 fathoms, it is normally sufficiently accurate to use predicted tides. This applies equally well to offshore and coastal surveys.

Where depths are less than 20 fathoms (and especially when they are 11 fathoms and below) tidal reductions must be more accurate. With the introduction of vessels drawing 60 feet or more deep laden, accurate reductions for all depths up to about 15 fathoms becomes very necessary.

In coastal surveys it has been shown that the problem of reduction is overcome simply by siting tide gauges along the coast and observing the tide. In offshore waters it may be possible to use drying banks, islets or temporary structures such as drilling rigs, as sites for tide gauges. In their absence, the ideal answer is to use automatic sea-bed tide gauges. In a large survey they may be disposed within the survey area in much the same way as are shore based gauges in a coastal survey (see Section **6d** above). Datum must be transferred from a suitable shore based tide gauge where it is already established (see **b** below). There will be no point in these circumstances in using the rigorous methods of transfer described in Section **6g** above, since in offshore waters it will very rarely be possible to cut a stable benchmark, to recover a datum for future use, or to transfer an established datum to another place. The analogy with a hanging traverse used for topographical work is almost exact.

Unfortunately, automatic sea-bed tide gauges have not as yet been fully developed (1966). The few available suffer from the fact that they are not very accurate, and are expensive. They are also rather inconvenient to lay and recover, and observations can only be extracted after recovery. There is likely to be a greater demand for them in the future, in which case the problems of design and production will be overcome. Some of the suggestions given in Section **8d** below may serve to stimulate interest and produce fresh ideas.

In the absence of a suitable automatic sea-bed tide gauge, tidal observations may be obtained from an anchored ship. Datum is transferred to the offshore tidal station occupied by the ship (see **b(ii)** and **(iii)** below); the position of the station must be accurately known, or it must be marked with a tightly moored danbuoy or floating beacon. Tidal readings, probably accurate to about ±1 foot, may then be obtained when required by a boat or ship taking soundings at the station.

In a large offshore survey three or more sets of tidal observations should be obtained in or around the area before sounding begins, and a small co-tidal chart constructed from the results in the manner described in **c(iv)** below. In order to reduce soundings observations must be obtained at one of the tidal stations and corrected in accordance with the co-tidal chart. This should give a reduction accurate to within about ±2 feet.

If a degree of accuracy lower than this is acceptable, reductions may be more conveniently obtained from distant shore based tide gauge readings which have been corrected in the manner described in **b(ii)** below. To minimise inaccuracies when using this method, the range at the shore based tidal station should be greater than the range in the survey area; this consideration should be borne in mind when selecting the shore tidal station which is to be used for transfer and comparison.

It should also be understood that tidal curves plotted from corrected observations obtained at a distant tidal station will be closest to the actual tidal height in the survey area over the low or high water periods; at about half tide when the tidal level is altering most rapidly inaccuracies are likely to be greatest. For this reason when reductions are being obtained in this manner, sounding in shoaler depths should only be carried out over high or low water periods.

As a check on the accuracy of the method used, it is recommended that soundings in flat, level areas should be taken at different states of the tide; discrepancies between reduced soundings at the different times will give an indication of the accuracy, as consistent soundings will mean that the method of reduction is good. If lines of soundings are interlaced in the manner described in Chapter 3, Section **24j (iii)**, this check may generally be obtained as the survey progresses.

b. Offshore tidal observations from a ship; obtaining datum and tidal reductions

(i) Offshore tidal observations from a ship. To obtain these tidal observations, the ship must be anchored in the survey area where the bottom is as flat as possible. To find a suitable position a careful reconnaissance will be necessary. A small area around the selected position must then be systematically sounded; this must be carried out rapidly and preferably near high or low water, otherwise a changing and unknown tide may well affect the results. For reasons given later, the unreduced soundings should be recorded on a large scale plot of the area.

The ship is then anchored in the flattest portion of the area examined and the rise and fall of the tide is observed with an echo sounder. This must have been recently bar checked carefully in the manner described in Chapter 3, Section **4d**, of this volume; the echo sounder's speed and index error must be checked frequently and regularly while observations are being taken.

To minimise inaccuracies caused by the sea-bed not being completely level, the swing of the ship may be reduced by mooring, or dropping a second anchor underfoot. It will be better, however, to use the large scale plot mentioned above; this method is particularly suitable if a sensitive electronic fixing system is being used to carry out the survey. To use the plot for this purpose the ship is fixed on it as each observation is taken, by the same means as that used to position the soundings; the tidal observation obtained may then be adjusted by the difference in depth between the position of observation and the precise position of the tidal station.

To take tidal observations from an anchored ship, it is recommended that the echo sounder should be read every 10 or 15 minutes; if this is inconvenient, readings may be taken every half hour. To maintain stability in the echo sounder, it should be kept running for the whole period of observation; to save paper it may be switched to fathoms, or the paper drive slowed down between actual observations. Readings should be recorded to the nearest half foot (or better if the equipment is suitable) at very short intervals over a period of about one minute covering the time of observations; these depths may then be meaned to give a result accurate to a fraction of a foot. The number of readings necessary in the minute period will depend on the accuracy required; when the echo sounder is read to half a foot, the following table shows the number of readings required to give the accuracy indicated:

NUMBER OF READINGS TAKEN OVER ONE MINUTE, EACH READ TO THE NEAREST 0·5 FEET	ACCURACY OBTAINED IN THE MEAN READING
	feet
30	0·1
20	0·12
10	0·17
5	0·25

The echo sounder having the most open scale should always be used, if more than one is available.

(ii) Obtaining datum and tidal corrections from offshore tidal observations when the tide is semi-diurnal. In the method described use is made of observations obtained from an anchored ship, but it may equally well be used for observations made with an automatic sea-bed tide gauge. For the reasons set out in Section **7a** above there will be no point in using the method of transfer described in Section **6g(i)**. Simultaneous observations must be taken ashore at a place where chart datum is already established; the range here should be greater than the range at the offshore station, in order to minimise inaccuracies.

The procedure is as follows:

(1) Take observations with the echo sounder to cover at least one high water and one adjacent low water (or preferably two of each).

(2) Plot the soundings obtained on squared paper. In Fig. 2–12(*a*) this has been done to give the circled points. Draw a smooth curve through the plotted points.

(3) For any completed half tidal cycle, that is between any recorded high water and its adjacent recorded low water, take from the curve the hourly depths. These are meaned to give M.S.L. In Fig. 2–12(*a*) the observations between 2250 and 1200 have been used and M.S.L. is found to be 65·3 feet above the sea-bed. Draw a horizontal line across the paper to represent this level. If datum alone is required, M.T.L. may be obtained here from observations covering the high and low water periods only.

(4) Plot on another piece of squared paper the tide readings above chart datum obtained at the established tide gauge ashore. The period covered must include the same high and low waters as those observed at the offshore station; deciding on the correct period may not be easy at times, and judgement is required. Draw a smooth curve through the plotted points, as in Fig. 2–12(*b*).

(5) Obtain M.S.L. by meaning the hourly heights. Draw a horizontal line across the paper to represent this level. In Fig. 2–12(*b*) it is 5·7 feet above chart datum. If M.T.L. is used in (3), it must also be used here.

(6) From the two curves obtain the mean ranges for the day at the tide gauge ashore and at the offshore station. In the diagrams, the mean range for the full tidal cycle 2250 to 1200 at the offshore station is 6·8 feet, while that for the same tidal cycle ashore is 8·0 feet. The ratio of ranges is then:

$$\frac{\text{Mean range at ship}}{\text{Mean range at gauge}} = \frac{6{\cdot}8}{8{\cdot}0} = 0{\cdot}85.$$

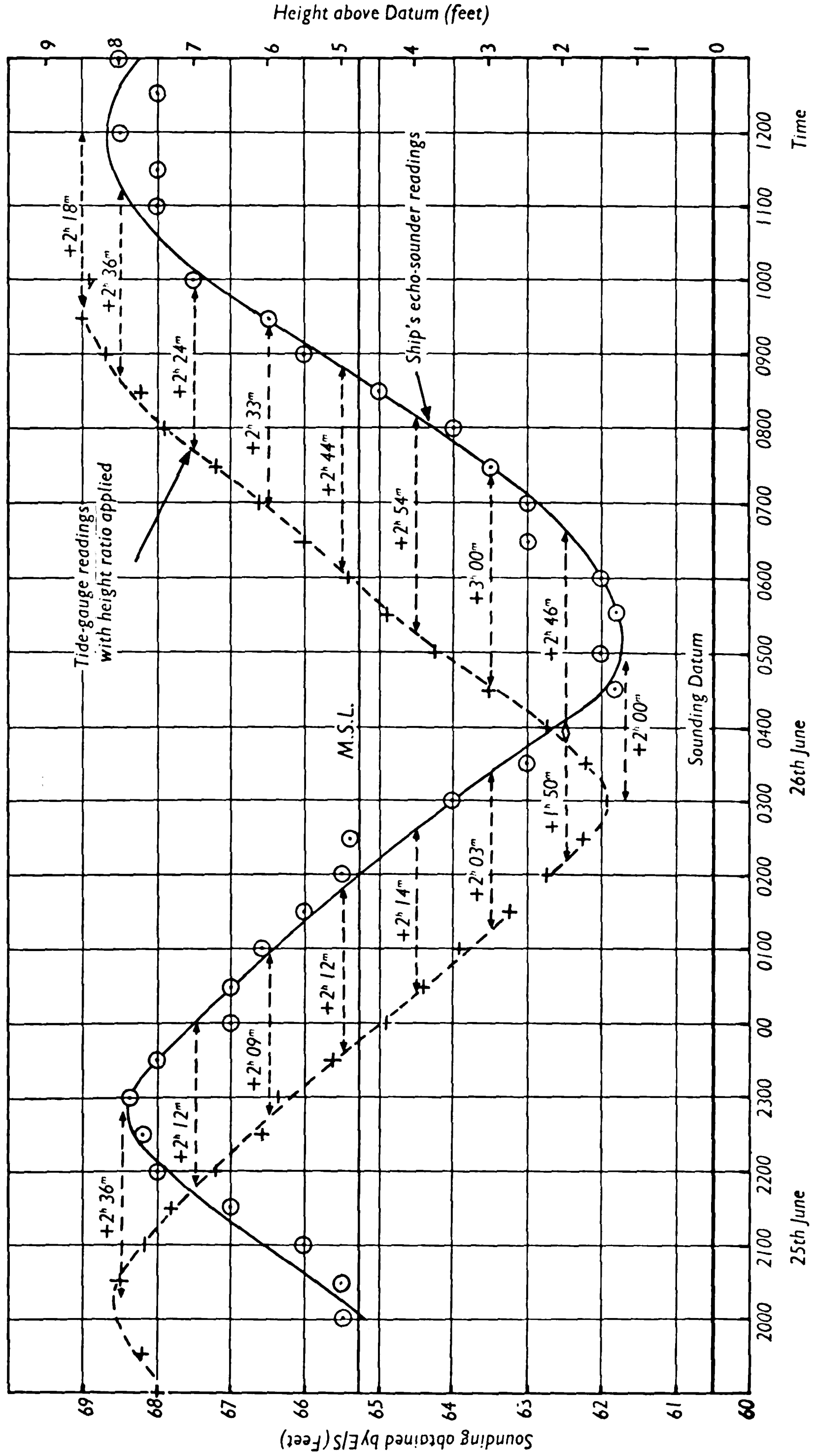

Height above Datum (feet)
9
8
7
6
5
4
3
2
1
0
Sounding obtained by E/S (Feet)
69
68
67
66
65
64
63
62
61
60
Time
2000
2100
2200
2300
00
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
1100
1200
25th June
26th June
M.S.L.
Sounding Datum
Ship's echo-sounder readings
Tide-gauge readings with height ratio applied
+2h 18m
+2h 36m
+2h 24m
+2h 33m
+2h 44m
+2h 54m
+3h 00m
+2h 46m
+2h 00m
+1h 50m
+2h 03m
+2h 14m
+2h 12m
+2h 09m
+2h 12m
+2h 36m

Fig. 2–12a

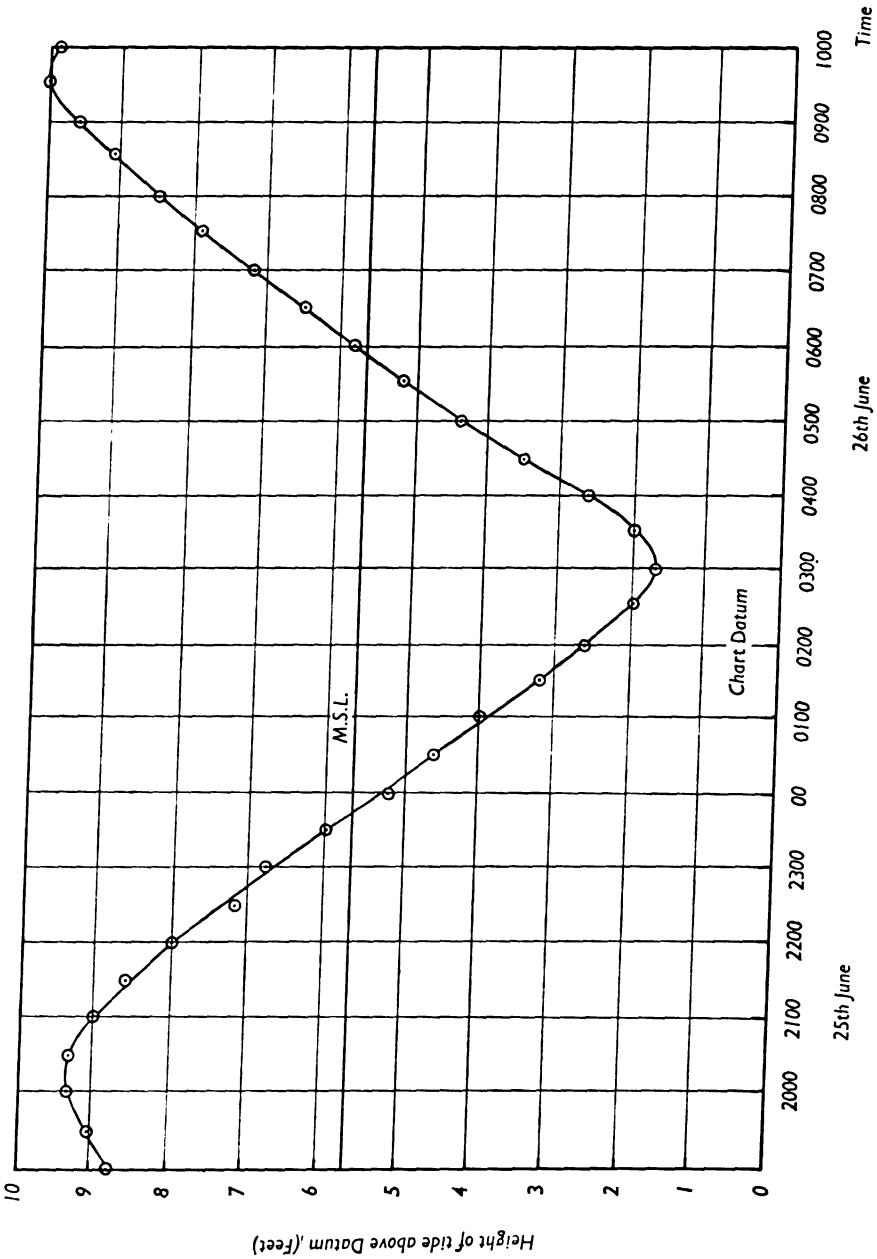

10
9
8
7
6
5
4
3
2
1
0
Height of tide above Datum, (Feet)
M.S.L.
Chart Datum
2000
2100
2200
2300
00
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
Time
25th June
26th June

Fig. 2-12b

(7) Apply the ratio obtained in (6) to the height of M.S.L. above chart datum at the shore gauge to obtain the height of M.S.L. above datum at the ship station.

(8) Insert chart datum on the ship station plot and add a new vertical scale of heights above chart datum. In Fig. 2–12(*a*) this transferred datum is 5·7×0·85 = 4·8 feet below M.S.L. and 60·5 feet above the sea-bed. The new vertical scale is shown on the right of the figure.

The position of the offshore tidal station must be marked with a tightly moored danbuoy after the ship weighs on completion of observations. Tidal observations for a tidal reduction curve may be obtained by taking soundings close to the buoy; a sounding boat may be left in the vicinity for this purpose or the ship may make periodic visits. The tidal heights required for the curve are obtained by subtracting the height of chart datum above the sea-bed from the soundings taken, i.e. in the example by subtracting 60·5 feet.

If it is desired to obtain reductions from readings taken ashore at the established tide gauge, then tidal corrections to be applied to these readings must be obtained. The ratio of ranges has already been obtained in (6) above. The time difference may be obtained in the following manner:

(*a*) Apply the ratio of ranges to the tide readings obtained at the shore gauge. Plot the corrected tidal heights above chart datum on the same plot as the observations taken at the offshore station, and draw a smooth curve through them. In Fig. 2–12(*a*) they are shown as crosses and the curve as a pecked line. In theory this curve should have the same shape and amplitude as the curve obtained from the ship's echo sounder readings, but it will be displaced in time.

(*b*) Time differences between the two curves at high and low water and at each intermediate foot level may then be taken off the diagram as follows:

CORRECTED HT. ABOVE C.D.	TIME DIFFERENCE CORRECTION TO GAUGE		CORRECTED HT. ABOVE C.D.	TIME DIFFERENCE CORRECTION TO TO GAUGE	
FALLING TIDE			RISING TIDE		
feet	*hr*	*min*	*feet*	*hr*	*min*
H.W. (approx. 8·0)	+2	36	L.W.	+2	00
7·0	+2	12	2·0	+2	46
6·0	+2	09	3·0	+3	00
5·0	+2	12	4·0	+2	54
4·0	+2	14	5·0	+2	44
3·0	+2	03	6·0	+2	33
2·0	+1	50	7·0	+2	24
L.W. (approx. 1·0)	+2	00	8·0	+2	36
			H.W. (approx. 8·5)	+2	18

Mean Difference: +2 hrs 17 mins.

If very accurate reductions for the area are required from the shore tide gauge readings, time differences appropriate to the height should be applied. If a lower degree of accuracy, introducing an additional error of possibly ±1 foot, is good enough, then for convenience a fixed time difference (the mean of all the values) may be used.

(iii) Obtaining datum and offshore tidal reductions when the tide is diurnal. When the tide is diurnal observations must be taken over a longer period. At least 25 hours' simultaneous observations are necessary at the offshore station and the established tide gauge ashore. It is important that the shapes of the two curves plotted from the observations should be very similar; if possible the tidal range at the shore gauge should be the greater.

To obtain datum the two sets of observations are analysed in accordance with *Admiralty Tidal Handbook No. 3*, and the four main harmonic constants obtained for each position. Chart datum is then transferred from the shore station in the manner described in Section **6g(ii)**. If *Admiralty Tidal Handbook No. 3* is not available and the harmonic constants are not known, sounding datum can always be established by the method described in Section **6h** of this chapter. The observations referred to above should always be obtained if possible, so that an analysis can be made later. Reductions for the area may then be obtained from soundings taken at the offshore station in the manner described in (ii) above.

Reductions may also be obtained in the following manner from observations made ashore at the tide gauge, but the degree of accuracy is likely to be less than with semi-diurnal tides:

(1) From the harmonic constants obtained from the analysis and using form *HD 289*, *Admiralty Prediction Form*, or a portable tidal prediction machine, compute the predicted tidal heights at both stations on the day. Plot the two predicted curves on two separate pieces of squared paper (the squared paper

TIDE AT SHORE STATION

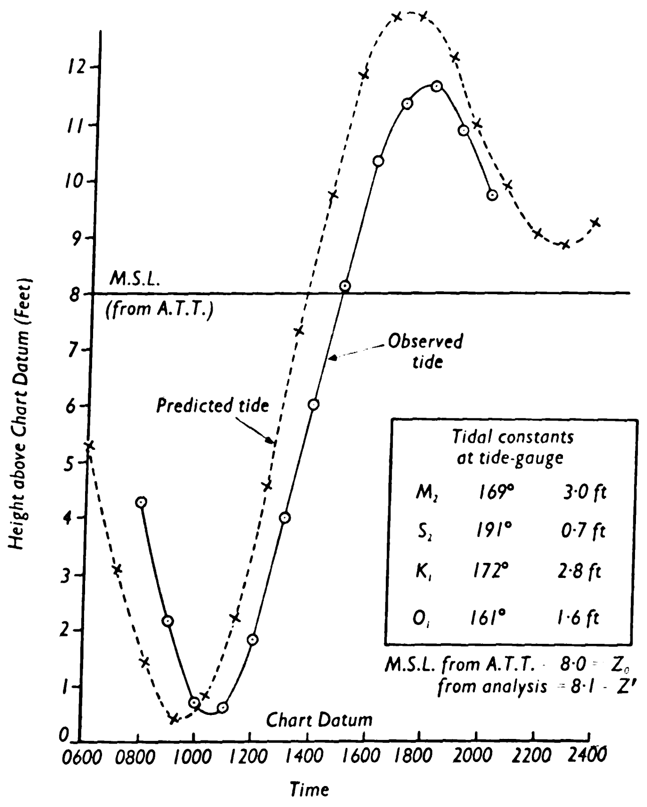
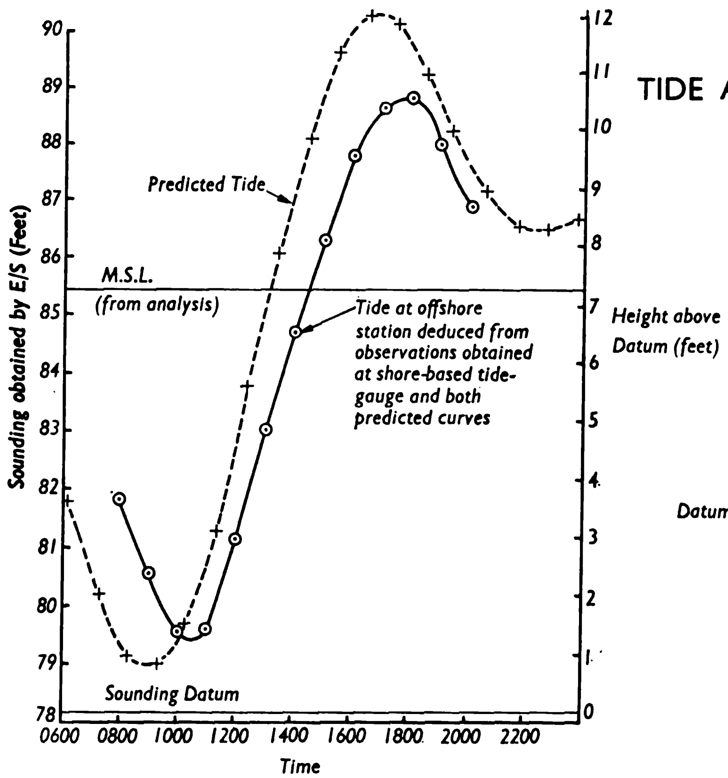


Fig. 2–13a



TIDE AT OFFSHORE STATION

Tidal constants at offshore station		
M_2	154°	2·5 ft
S_2	174°	0·6 ft
K_1	159°	2·7 ft
O_1	149°	1·5 ft

M.S.L. from analysis
$z' = 85{\cdot}5$ *ft above sea bed*

$$\text{Datum} = z' + (Z_0 - Z') - Z_0 \times \frac{h}{H}$$
$$= 85{\cdot}5 - 0{\cdot}1 - 8{\cdot}0 \times \frac{7{\cdot}3}{8{\cdot}1}$$
$$= 85{\cdot}4 - 7{\cdot}2$$
$$= 78{\cdot}2 \text{ ft}$$

Fig. 2–13b

provided on form *HD 289* will be suitable); these are shown as pecked lines in Figs. 2–13(*a*) and (*b*).

(2) Draw the observed tidal curve obtained at the tide gauge ashore on the appropriate plot. It is shown as a full line on Fig. 2–13(*a*).

(3) Take off discrepancies in height between the predicted and observed curves at half-hourly intervals and at high and low water.

(4) Apply these height discrepancies to the predicted curve at the offshore station for the same time. In practice, steps (3) and (4) may be combined by transferring height discrepancies from one diagram to the other with dividers. The resulting curve, shown in Fig. 2–13(*b*) as a full line, may be used for the reduction of soundings.

This last step presupposes that any discrepancy between the predicted and observed tides at the tide gauge, which may be due to weather and other causes, has the same value at the same time at the offshore tidal station. Although this supposition will not always be correct, it is probable that the curve obtained in this way will be an improvement on the predicted curve, especially if the shore station is reasonably near. It is as well, however, to check the local conditions at a particular offshore tidal station by taking additional tidal observations with the echo sounder for a few hours at different stages of the tidal cycle. In this way a more accurate reduction curve may be produced by combining local observations with corrected readings from the distant gauge, and applying additional empirical corrections if these are required.

c. Co-tidal charts

(i) General description; types of co-tidal chart. There are two types of co-tidal chart. The first is the more common and easier to use but is only suitable for semi-diurnal tides; on it two sets of curves connect points having equal ranges and points having simultaneous high and low waters. It may be used to convert predictions or observations made at any point on it, to any other point.

The second type of co-tidal chart is suitable for all types of tide; since it is more difficult and inconvenient to use it is normally made only for diurnal tides which cannot easily be represented in any other way. Four separate charts are needed to cover a particular area; each will show two sets of curves which connect points having equal amplitude (half the range) and phase lag (a measure of time), for a particular harmonic constituent. The constituents used are M_2, S_2, K_1, and O_1. From these charts the values of the four main harmonic constituents may be interpolated for any position, and a predicted tide may then be computed with the aid of a portable predicting machine or on form *HD 289*, *Admiralty Tidal Prediction.*

Most of the information on which present day co-tidal charts are based comes from observations obtained ashore. The inshore ends of co-tidal curves should therefore be reasonably accurate. Comparatively few offshore tidal observations have been obtained, and therefore co-tidal curves in offshore waters will usually have been sketched in between observations obtained on facing coasts, with some assistance from tidal stream observations. Thus for a broad channel, like the Irish Sea, the co-tidal chart is based mainly on tidal observations taken on opposite coasts; mid-channel curves will have been sketched in using them and tidal stream observations, together with a few offshore observations obtained on islands. As more tidal information becomes available from ship observations or offshore tide gauges, it will be possible to produce better co-tidal charts for offshore waters.

Co-tidal charts are generally published for areas where tidal conditions alter rapidly and where shipping is concentrated. The surveyor may construct his own chart from information in the *Admiralty Tide Tables* and that which he has himself obtained. It will be very useful in an offshore survey area, particularly if this is large. If a published chart is used the co-tidal curves within the survey area should be checked by taking as many off-shore observations as possible.

The semi-diurnal and diurnal types of co-tidal chart are described in **(ii)** and **(iii)** below. A method of constructing an original chart is described in **(iv)** below.

(ii) The semi-diurnal co-tidal chart. A typical semi-diurnal co-tidal chart is shown in Fig. 2–14. All the co-tidal curves indicate relationships to the tide at the Standard Port *A*, where the range is large compared with that in most of the rest of the area. The full lines indicate time corrections which must be applied to the times of the tide at *A*; thus the time of high or low water at *B* is 30 minutes earlier than it is at *A*, while at *C* it is 30 minutes later. The pecked co-range lines give range ratios on the tide at *A*; thus at *B* the tidal range is 0·65 times the range at *A*.

It must be assumed when making the chart that the times of high and low water at a particular place both differ by the same amount from those at the standard port. If the tide was truly semi-diurnal this assumption would be valid. In practice, when even a 'semi-diurnal' tide is affected by slight diurnal inequality, these time differences will not be exactly the same, and it will be necessary to use a mean value. Clearly the greatest errors of height caused by this will occur at half tide.

The co-range values refer to the range of the tide at any particular point. They may be applied directly to heights above datum, which will then automatically be changed in the correct manner throughout the area covered by the chart.

Thus at *B*, high water will occur 30 minutes earlier than at *A*, and its height (relative to the correct datum at *B*) will be (height at *A*) × 0·65.

If for any reason chart datum has previously been established at *B* without reference to datum at the standard port *A*, it may have an incorrect value. In this case it will

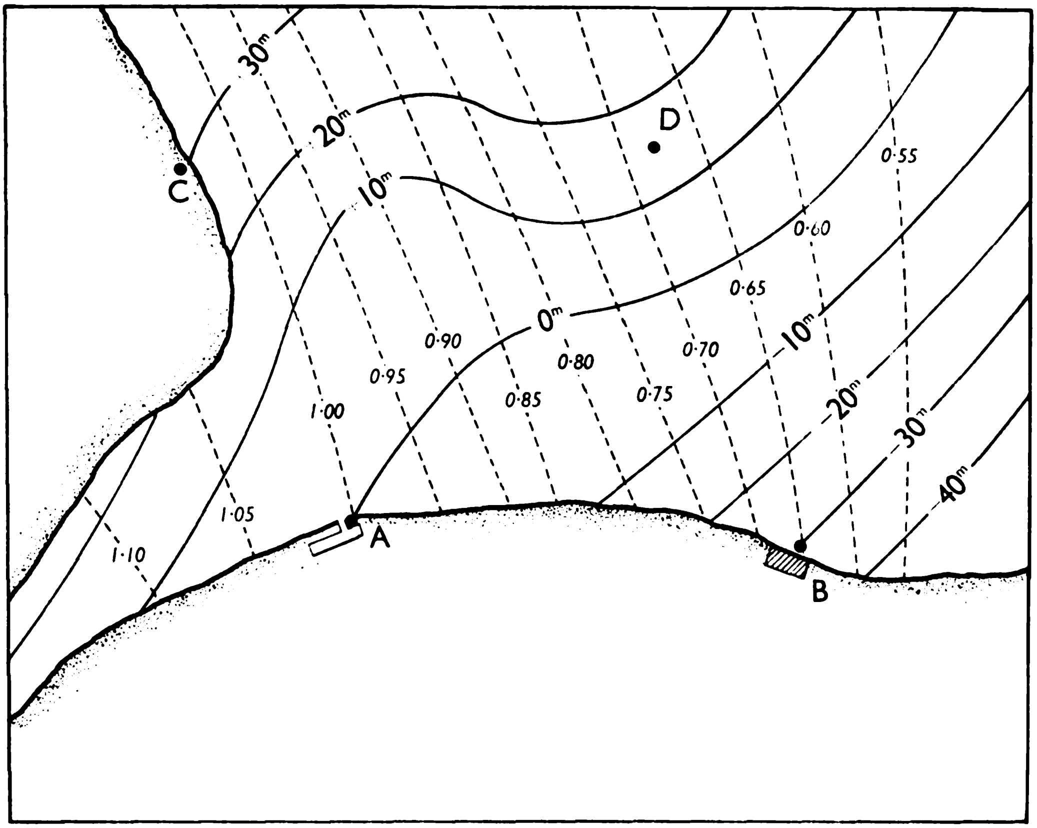


Fig. 2–14

be imperative to use a ratio of ranges and values of mean sea level at the two places, when calculating tidal heights at *B* relative to this unconnected and possibly incorrect datum.

For example, suppose that the spring range at *A* is 12·3 feet and that at *B* is 8·0 feet. The height of M.S.L. above datum at *A* is given as 7·2 feet, while that at *B* is given as 4·0 feet. If chart datum at *A* (which is below M.L.W.S.) has been established correctly, then the datum at *B* (which approximately at M.L.W.S.) is incorrect.* To convert a tidal height at *A* to a tidal height at *B* above its incorrect datum, proceed as follows:

(1) Obtain the difference between the height of tide at *A* and M.S.L. For a height of tide of 4·3 feet, this is 7·2−4·3 = 2·9 feet.

(2) Obtain the height of tide below (or above) M.S.L. at *B* by multiplying the value obtained in (1) by the ratio of ranges. In this case 2·9 × 0·65 = 1·9 feet, and the equivalent tidal height at *B* is 1·9 feet below M.S.L.

(3) Obtain the height of tide at *B* by applying the height of the tide obtained in (2) to the value of M.S.L. above datum. The equivalent height of tide at *B* is thus 4·0−1·9 = 2·1 feet. above datum.

If the datum at *B* had been established correctly with reference to *A*, then it would have been permissible to apply the ratio direct to the tidal height at *A* to obtain the height at *B*.

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* The correct datum at *B* is 7·2 × 0·65 = 4·7 feet below M.S.L. This should, of course, always be used except in exceptional circumstances, as, for instance, when it is desired to compare new work directly with old soundings based on an incorrect datum.

Sometimes time differences are given in the form of intervals of time after the moon's transit at Greenwich (lunitidal intervals) and co-range lines indicate actual values of range.

Observations from any tide gauge may be used in conjunction with this type of co-tidal chart to reduce soundings. The closer the gauge can be to the sounding area, the better, since errors caused by changing meteorological conditions will then be reduced as much as possible. The surveyor should never take the accuracy of a co-tidal chart for granted, especially in offshore areas. He should check it as much as possible by carrying out observations, even if these only consist of a few sets of echo sounder readings taken from a ship at anchor.

Suppose that in Fig. 2–14 the surveyor has satisfied himself that the co-tidal lines around the position *D* are reasonably accurate. He may have amended them slightly in the light of his observations (details of these observations must of course be included in his report of survey). Soundings obtained at *D* may then be reduced from tide gauge readings obtained at *A* by adding 15 minutes to all times, and multiplying all heights by 0·68, to obtain the tidal curve.

Observations obtained at *B* could be used instead, but in that case there would be a slight reduction in accuracy, since the range at *B* is smaller than it is at *D*. The time correction to be applied would be $+15-(-30)$ or $+45$ minutes and the ratio would become 0·68/0·65 or 1·04.

Instructions on the preparation of a reduction curve using a co-tidal chart are given in Section **9d** of this chapter.

(iii) The diurnal co-tidal chart. An example of a diurnal co-tidal chart for the M_2 harmonic constituent is shown in Fig. 2–15. The full lines connect points having equal values of phase lag (g), which is given in degrees and which is in effect a measure of time. The pecked lines indicate the semi-range or amplitude (h) of the M_2 tide in feet. Thus for the position X, the value of the M_2 constituents is $g = 291°$ and $h = 0·23$ foot.

The M_2 chart by itself is of little value. Three others are necessary, showing co-tidal values for S_2, K_1, and O_1. Using the set of four charts, values of phase lag and amplitude may be obtained for the four principal constituents of the tide at any point; these may then be used to predict the tide at that point.

This type of co-tidal chart cannot be used to convert tide readings obtained in one place to those applicable in another, except possibly in the manner described in **b(iii)** above. This method is not very accurate, and should only be used in exceptional circumstances. Its accuracy will, however, be greatly improved if a few observations can be taken on the spot at different states of the tide. The predicted curve may then be amended as necessary to fit these observations.

When the tides are diurnal the surveyor should always observe them in his sounding area, unless this is quite impossible.

(iv) Constructing a co-tidal chart. A semi-diurnal co-tidal chart may be constructed by the surveyor provided that time differences and tidal ratios are available for at least three suitable positions. These should if possible enclose the sounding area within an equilateral triangle. The more positions that are available, the more accurate will be the chart.

Figs. 2–16(*a*) and (*b*) show a large survey area which lies some 20 to 50 miles offshore. Reductions for soundings in this area will be obtained from observations taken at *A* (a secondary port) where chart datum is established. *B* and *F* are two other secondary ports. The time differences and ratios at *A*, *B* and *F*, relative to the same

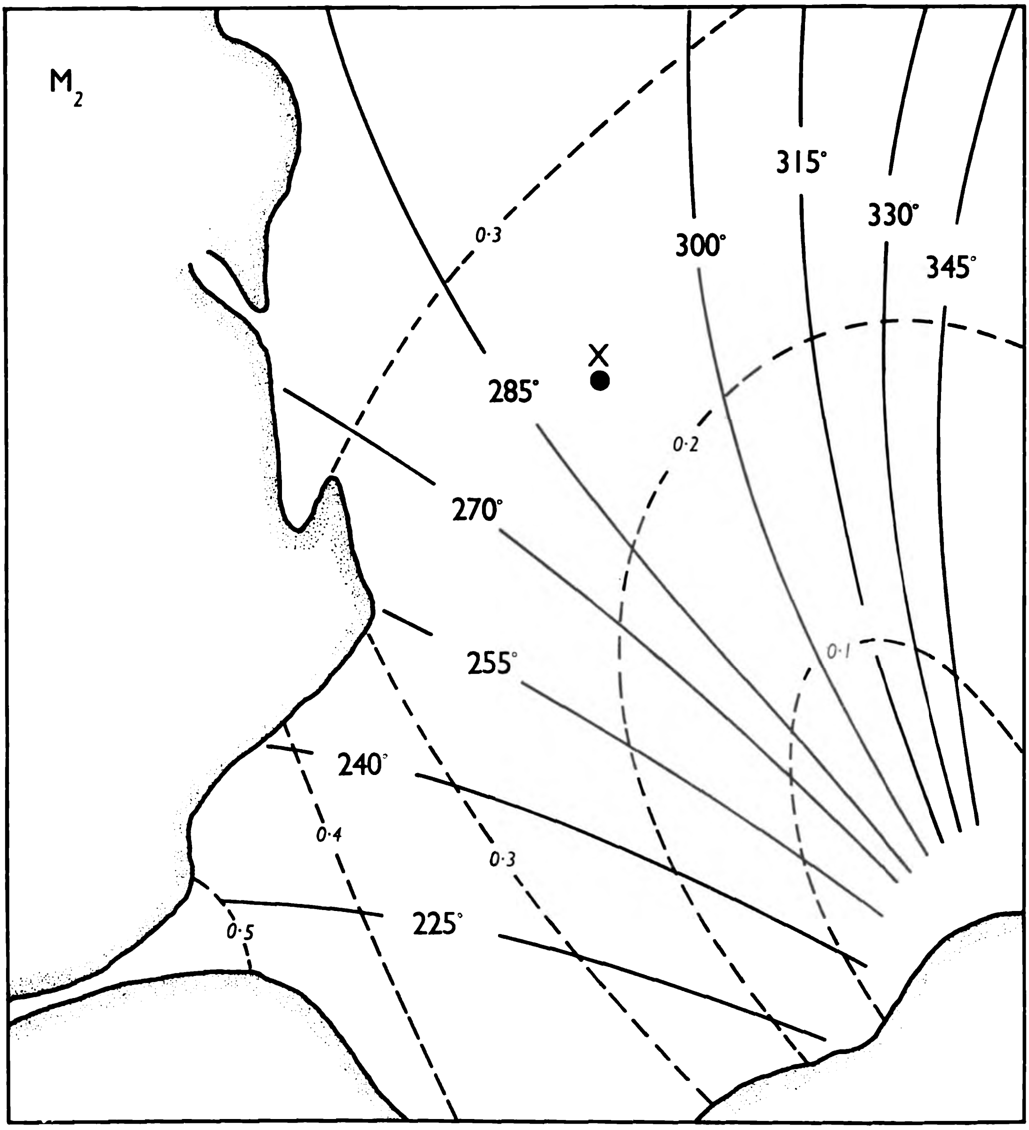

Fig. 2–15

standard port,* may be extracted from *Admiralty Tide Tables Part II*. These may be adjusted so that A becomes the local 'standard port', with zero time difference and a ratio of 1·00. The local time differences and ratios at B and F are shown in the figures.

To construct a co-tidal chart using this information, proceed as follows:

(1) Carry out offshore tidal observations at D (see **b(ii)** above), a position which together with A and B forms an approximately equilateral triangle enclosing the survey area. A position forming an equilateral triangle with B and F could equally well have been chosen.

(2) If possible, obtain additional tidal observations at other stations within or

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* If A, B, and F are not related to the same standard port, their time differences and ratios will not be equatable.

CONSTRUCTING A CO-TIDAL CHART–TIME CURVES

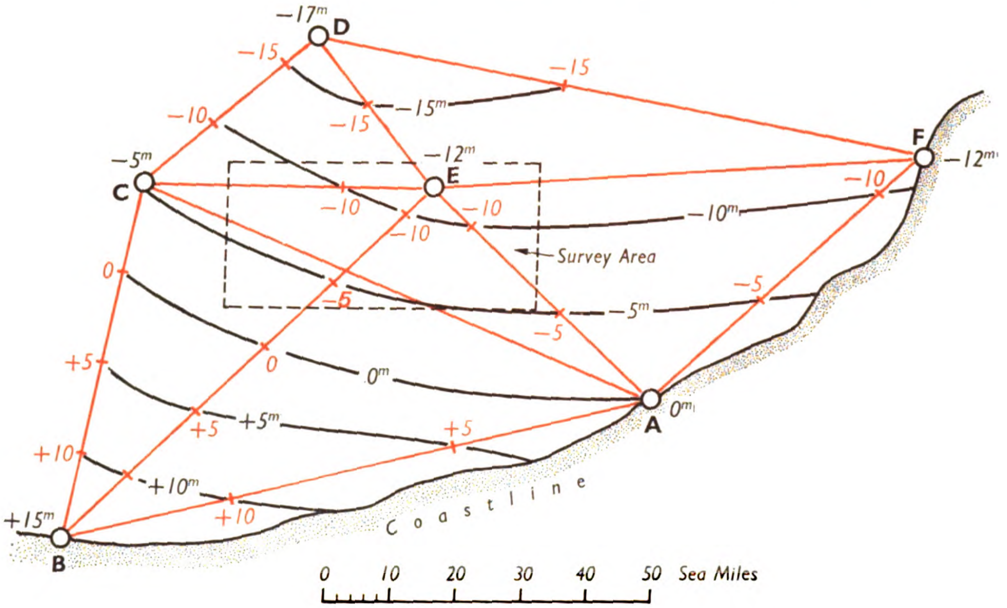


Fig. 2–16a

CONSTRUCTING A CO-TIDAL CHART–RANGE CURVES

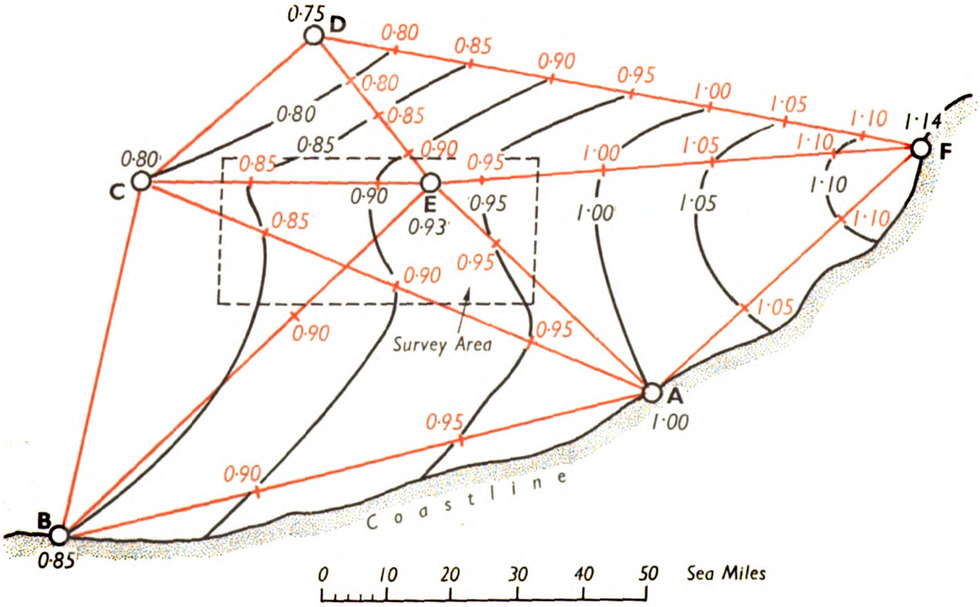


Fig. 2–16b

around the survey area. These will provide additional control. In this particular example additional observations have been taken at *C* and *E*.

(3) Obtain tidal corrections on the tide at *A* for all the positions at which observations have been carried out.

Then, for the time curves, and referring to Fig. 2–16(*a*):

(4) Join adjacent tidal stations with straight lines, and interpolate time differences along these lines. The lines and interpolated times are shown in red in the diagram.

(5) Sketch in the time difference curves; these are shown in black in the figure, and it can be seen that the survey area is well covered.

(6) Repeat this process for the range curves, to obtain the results shown in Fig. 2–16(*b*).

Common sense and judgement are required when these curves are being drawn, if errors are to be reduced to a minimum. Note that the 0·90 interpolated point on the line *BE* in Fig. 2–16(*b*) has been disregarded, preference being given to its neighbour on the line *AC*. Interpolated points will always be more reliable if the line on which they lie cuts the curves being drawn at a broad angle. Similarly points on a short line will always be better than those on a long line.

Suppose now that tidal observations have been obtained at *A*, *B* and *D* only. Co-tidal curves may still be drawn, but they will not be so reliable as the ones described above. Consider the lines *DE* and *EA* in Fig. 2–16(*b*). If values were interpolated along them, neglecting the observed value at *E*, the result would be quite different from that shown.

8. Tide Poles; Automatic Tide Gauges

a. Tide poles

(i) Description; design. A tide pole, which is a simple type of tide gauge, is a graduated pole which is set up vertically in the water, so that the changing level of the sea surface may be read on it as the tide rises and falls. It may be graduated in fractions of a foot or a metre.

A typical tide pole is shown in Fig. 2–17. It consists of a 10 or 15-foot length of timber, about two by four inches in cross section, graduated in feet. The even foot intervals are painted black with white figures and markings while the odd feet are white with black figures and markings. The sub-divisions are short horizontal lines, extending about one-sixth of the width of the pole face, and spaced at 0·2 foot intervals; readings can be estimated to 0·1 of a foot. To facilitate repainting the pole, the graduations are scored into its face with V-shaped grooves. The figures painted on the pole are just under six inches high, and are so placed that the top of each figure is exactly at the 0·5 foot level.

Each section of tide pole is fitted with a metal sleeve, about two feet long, at its top end so that another section may be connected. It is therefore a simple matter to make up a pole of any length. Care must be taken to ensure that adjoining sections of pole fit properly; in Fig. 2–17 the 10 and 12 foot graduations on the different sections which straddle the joint must be exactly two feet apart.

To make it easier to read the pole at night, 'catseye' reflectors may be let into the pole at each graduation mark, reflectors of different colours being used to indicate odd and even whole foot markings and 0·2 sub-divisions. Some of the figures themselves may also be picked out in reflectors. A powerful torch or signalling lamp is required for reading the pole at night.

(ii) Setting the zero of a temporary tide pole. Permanent tide poles in harbours and ports are normally set so that the zero of their graduations is at chart datum, or

A TYPICAL TIDE POLE

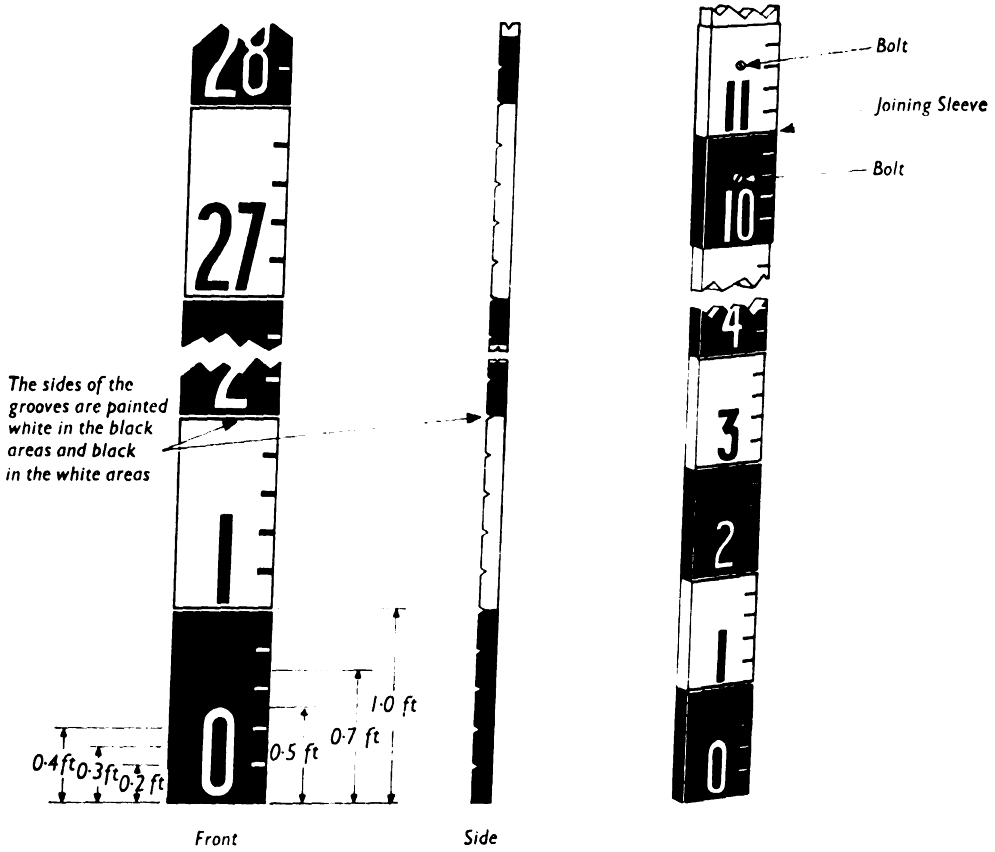

28
27
The sides of the grooves are painted white in the black areas and black in the white areas
1
0
0·4 ft
0·3 ft
0·2 ft
0·5 ft
0·7 ft
1·0 ft
Bolt
Joining Sleeve
Bolt
11
10
4
3
2
1
0
Front
Side

Fig. 2–17

at the level of the sill of a lock or basin entrance. Readings on these poles therefore indicate either the actual height of the tide or the actual depth of water over a sill.

There is no need to set the zero of a temporary tide pole used in survey work to any particular level so long as it is somewhere below sounding datum. If datum has never been established and no tidal information for the site of the pole is available, the surveyor must use his common sense. The following method is suggested:

(1) Estimate the spring range from *Admiralty Tide Tables Part II* by interpolating between secondary ports on either side of the site.

(2) Estimate the height of M.H.W.S. from local signs, such as the maximum height at which weed or marine growth is found, or the highest level to which flotsam is thrown up on a beach.

(3) Set the zero of the pole a few feet below the estimated level of M.L.W.S. A level will probably be required to do this.

(4) An alternative method, if the height of the tide can be predicted, is to set the pole so that it reads a few feet more than the predicted value at the time of erection. It is important to ensure that a tide pole never dries out at low water (but see (iii)(*c*) below).

(iii) Selecting a site for a tide pole. When selecting a site for a tide pole, the following points should be considered:

(*a*) Proximity to the Survey Area. The site must be in (or very close to) the survey area, but see Section **7** above for surveys in offshore waters and for the change of sounding datum in large areas.

(*b*) Ease of Erection. A solid permanent structure in the water, such as a pier, will always be the obvious and generally the best choice for a site. It is usually a simple matter to nail, lash or clamp a tide pole to the pile of a pier. On shelving, open beaches, groynes or stranded wrecks may be of considerable assistance.

(*c*) The Zero of the Pole must not Normally Dry Out. It sometimes happens that a particularly convenient site for a pole does dry out; if it is used then a second pole must be erected in deeper water to cover the lower levels of the tide (see (v) below).

(*d*) Ease of Reading the Pole. It is very necessary to be able to read the pole easily at all states of the tide. This factor may well have an effect on the accuracy of the readings, especially if the comfort of the tide watcher is also considered.

(*e*) Proximity of Suitable Accommodation for Tide Watchers. This consideration is of particular importance when the period of observations is to be long. If it is intended to land the tide watcher daily a pier or jetty is obviously the ideal site.

(*f*) Shelter. In order to read it accurately, and for its own protection, a tide pole should be erected in a position sheltered as far as possible from the effects of sea and swell. A sheltered position can often be found in the lee of a headland, in a small cove or bay, or behind a bank or breakwater.

(*g*) Impounded Water. Water is impounded when it is cut off from the open sea as the tide drops. The level within a basin of impounded water will not fall to the true level of low water, and there will be an apparent stand over the low water period when none occurs in open tidal waters outside. Water may well be impounded above the bar of a river, or in the deep channel of a stream which appears to have direct access to the sea, but which is in fact running down a slight incline across an open beach. A basin which is likely to impound water should be avoided as a site for a tide pole, unless it is possible to erect a secondary pole in open water. Note that it is possible for impounding to occur only at very low spring tides.

(*h*) Proximity of Existing Benchmarks. Where a national or local land datum exists, the tide pole should be erected, if possible, reasonably close to a benchmark. If chart datum has already been established in an area, there should be no difficulty in recovering the former tide pole site, which will probably be reasonably close to the benchmark.

(*i*) Stability. Unstable sites where subsidence, silting or scouring occur should be avoided if possible.

(iv) Erecting a tide pole on a pier or jetty. The erection of a tide pole on a pier or other permanent structure is largely a matter of common sense. The surveyor must ensure that:

(*a*) The pole is vertical, using wedges if necessary. If it is impossible to erect the pole in a vertical position, the angle of tilt must be measured so that tide pole readings may be corrected. See Volume 1, Chapter 9, Section **8c(iii)**, and Section **9a** of this chapter.

(*b*) The pole will not move, especially in a vertical plane. As a check a reference mark should be made on the supporting pile alongside a specific height on the pole.

PYRAMID SUPPORT FOR A TIDE POLE

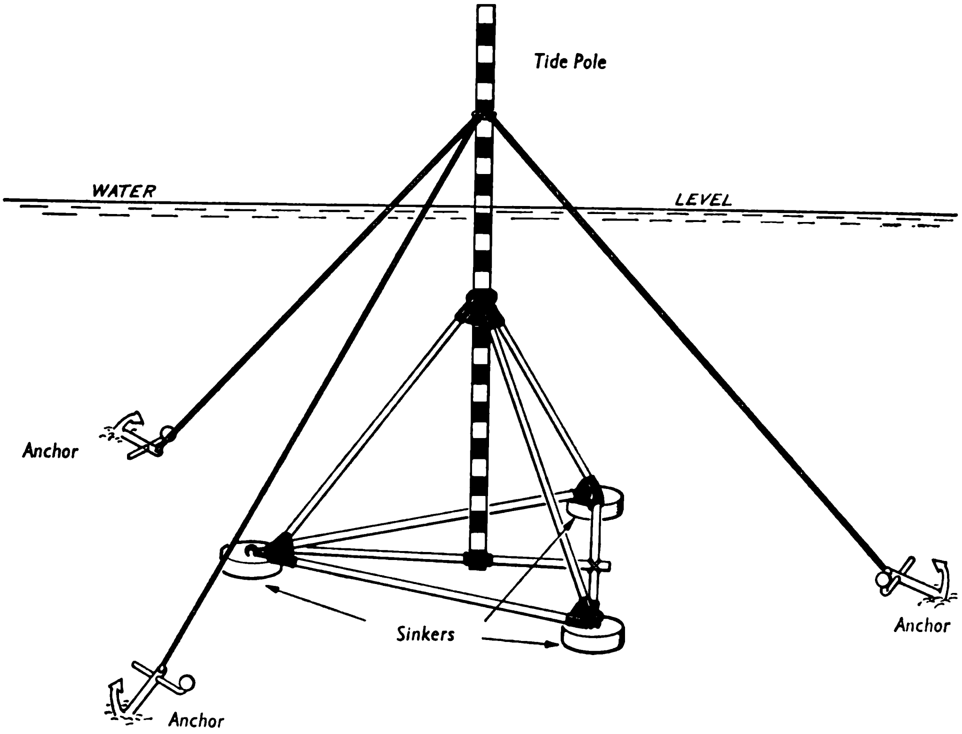


Fig. 2–18

(*c*) The pole is facing in such a direction that it can be read easily by a tide watcher.
(*d*) The pole is secured in a position where it can be levelled to conveniently.
(*e*) The pole will not be disturbed or damaged by vessels berthing on the pier.

If possible the pole should be erected at low water; if it happens to be spring tides, so much the better.

(v) Erecting a tide pole on an open beach or in shallow water. It is not easy to erect a tide pole on an open beach or in shallow water, especially if the range is large and the tidal streams are strong. It will therefore almost always be essential to carry out all operations at low water. Although the pole itself may be strong and rigid, extra support will usually be necessary if it is more than 10 or 15 feet in length. A supporting structure forming a tripod or small tower can be constructed from tubular scaffolding. This may be built ashore and raised in shallow water like a mast, with the upper end of the tide pole lashed in place; when the structure has been secured in position with guys, the tide pole should be secured vertically by lashing the heel or fitting a heel-weight. Alternatively a pyramid structure, made up of equilateral triangles, may be prefabricated on board and taken to the site by boat. It can be tipped into the water, since it will be immaterial which way up it lands on the bottom. A tide pole can then be lashed in place by waders or shallow water divers (see Fig. 2–18). If additional stability is required sinkers may be lashed to the three bottom corners of the structure, and guys laid out from the pole to anchors or sinkers.

When the range is large and the beach shelves gently, a pole placed to register

TIDE POLES ON A GENTLY SHELVING BEACH

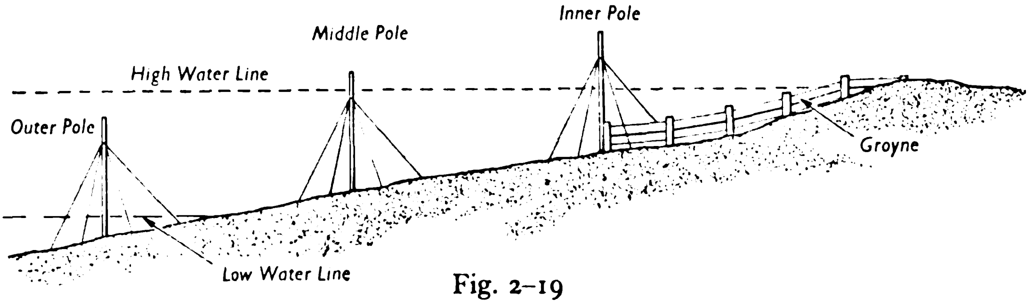


Fig. 2–19

low water readings may be so far from the water's edge at high water that it becomes impossible to read it from the shore. It will then be necessary to erect two or more poles at different levels to cover the full range of the tide (see Fig. 2–19). It is important that each pole should overlap its neighbour in the vertical plane; their relative levels must be determined by levelling, or from simultaneous readings of the water level on a calm day. Relative levels should also be checked twice per tide by reading two poles whenever possible.

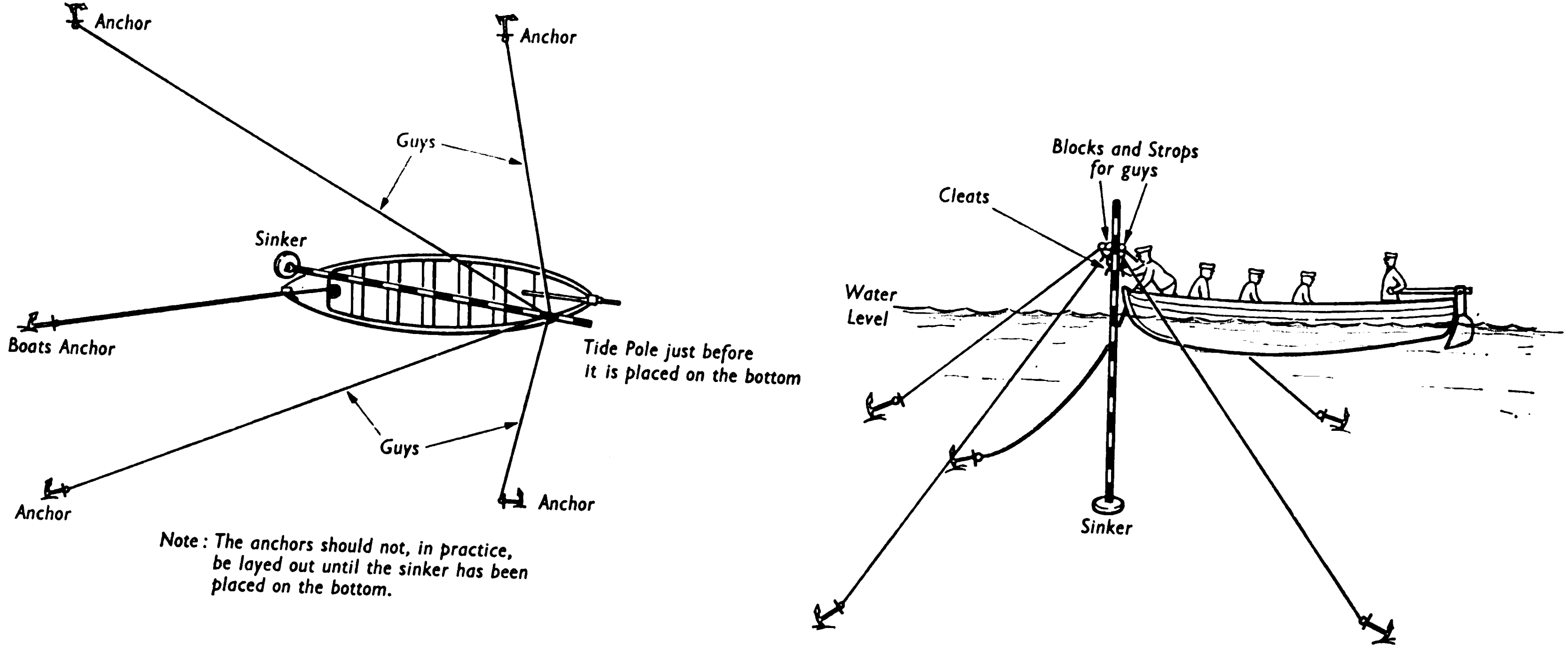
A tide pole unsupported by an additional structure may be erected easily from a boat where the water is shallow and the bottom is flat. An open boat about 30 feet long is ideal for the job. The following equipment is required:

(*a*) The tide pole. To its heel is lashed a heavy sinker and to its head two short wire strops. It is placed in the boat with the heel forward.
(*b*) Four wire guys, each at least five times the length of the tide pole.
(*c*) Four heavy boat's anchors and sinkers.
(*d*) Two cleats to secure the guys; if these are not available, four six-inch nails may be used. They should not be fitted to the pole yet.
(*e*) If available, four small blocks to take the wire guys.

The boat, together with an attendant dinghy, is taken to the chosen site and anchored; if there is no tidal stream to lie to, the dinghy should be used to lay out a stern anchor from the boat. To erect the pole, proceed as follows (see Fig. 2–20):

(*a*) Lay the tide pole diagonally across the boat with the heel hanging over the bows.
(*b*) Prepare the guys by reeving each pair through one of the wire strops at the head of the pole. If the four small blocks are available, a pair of blocks may be secured to each strop and each guy reeved separately through its own block.
(*c*) Slide the pole over the side and place the heel on the bottom so that the pole is in a convenient position to handle from the boat.
(*d*) Attach the guys to the anchors, and lay the latter out from the attendant dinghy. It is very important that the anchors are placed so that they lie on the corners of a square whose centre is the heel of the tide pole; if this is not done, it will be difficult to set the pole upright and the pole may be insecure. The anchors may have to be backed up with sinkers if the holding ground is not good.
(*e*) From the boat haul the guys taut. If the anchors are correctly placed, the pole should go up easily. Then secure the cleats to the tide pole at a convenient level above water; the guys should be adjusted to that the pole is vertical and then belayed to the cleats.

LAYING A TIDE POLE FROM A BOAT


Anchor
Anchor
Guys
Sinker
Boats Anchor
Tide Pole just before it is placed on the bottom
Guys
Anchor
Anchor
Blocks and Strops for guys
Cleats
Water Level
Sinker

Note: The anchors should not, in practice, be layed out until the sinker has been placed on the bottom.

(a) Setting up the Pole

Fig. 2–20

(b) Adjusting the Guys

b. Damped float tide gauges

A damped float tide gauge is designed to damp out the effects of sea and swell. It will be useful if the tide gauge site is exposed to the weather, especially when the tidal range is small compared with the amplitude of the sea or swell.

A typical portable damped float tide gauge is shown in Fig. 2–21. It may be made on board, and consists of a tube which is closed with a circular, bolted plate at its bottom end; there is a small inlet hole in the side a few inches above the bottom. The length of the tube must be a few feet more than the range of the tide.

Inside the tube is a float, which may be any shape or size provided it fits loosely so that it cannot stick, and can easily support in water the weight of the light rod secured to its upper end. This rod carries an inverted scale with zero at the top. It should be

A DAMPED-FLOAT TIDE-GAUGE

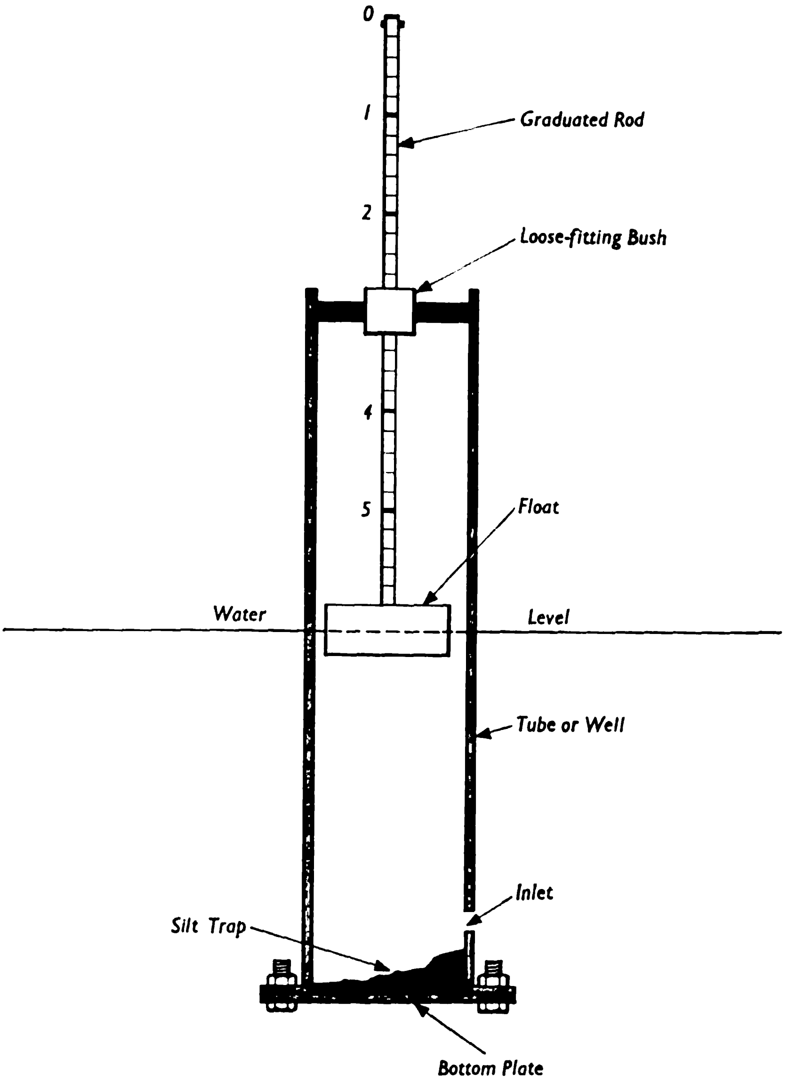


Fig. 2–21

a fairly loose fit in a bush fitted to the top of the tube. The tide reading is obtained by reading the rod graduations, which increase downwards, against the top of the tube or a fixed pointer. The sensitivity of the gauge varies directly with the cross sectional area of the float; the larger the area, the more sensitive the gauge becomes. It is essential that the tube should be set up vertically.

The size of the inlet hole is very important. It must be small enough to restrict the rate of flow of water sufficiently to damp out the short term effects of sea and swell, and yet big enough to ensure that the water level inside the well is the same as that outside. For most tidal ranges the cross sectional area of the inlet should be about one-hundredth that of the tube; a larger inlet will decrease the damping effect, but may be required for very large ranges.

The bottom of the tube below the inlet hole will form a silt trap; the silt must be cleared away from time to time. The inlet hole and the inside of the main tube must also be cleaned at regular intervals, as they will both be attractive sites for the growth of barnacles and other marine organisms.

When the gauge is set up, the inlet hole must be positioned so that it is a few feet below the level of the lowest possible tide in order to make certain that there is always water in the tube and the float is never in danger of grounding on the bottom of the well

Sometimes the tube is made of transparent material with the graduations marked on the outside; a brightly coloured pointer painted or fitted on the float can then be seen through the tube, and indicates the tide reading.

c. Automatic tide gauges

An automatic tide gauge usually records tidal height against time, on graph paper. Time is obtained from an electric or clockwork driven mechanism which is made to revolve a drum or disc; the system is usually so designed that one revolution represents 24 hours. In some recorders the record is made on a long sheet of paper, which is wound from one roller to another. With most recorders the record paper is supplied specially printed with time and height scales. A few recorders produce a record on blank paper on which the timing mechanism indicates the whole hour by punching a hole or with a separate recording pen.

The height recording mechanism is normally operated by either a float actuated or a pressure sensitive system. As these two types of gauges work on different principles and have slightly different characteristics and uses, they will be described separately.

Whenever an automatic tide gauge is used, a tide pole should be erected close by so that direct checks can be made periodically.

(i) Float actuated automatic tide gauges. Fig. 2–22 shows the layout of a simple float actuated automatic tide gauge. The float operates in exactly the same way as the float in the damped float tide gauge described in **b** above; all the remarks in that sub-section concerning sensitivity, size and position of inlet hole, and length of well tube are equally applicable to the automatic version. The well must be truly vertical.

The vertical movement of the float is transmitted by a thin wire which passes a least once round the gauge wheel.* The end of the wire is secured to a counterweight. This must be heavy enough to turn the gauge wheel when the tide is rising but not so heavy that it lifts the float appreciably out of the water when the tide is falling. Friction in the system must be reduced to a minimum. In this particular case, the counterweight will rise and fall the same amount as the float. To enable it to do this in air it is often enclosed in another vertical tube, which must be completely watertight. In order to do without the second long tube, the counterweight may be made

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* Sometimes a thin tape is used, perhaps in conjunction with a sprocket wheel.

FLOAT-ACTUATED AUTOMATIC TIDE-GAUGE

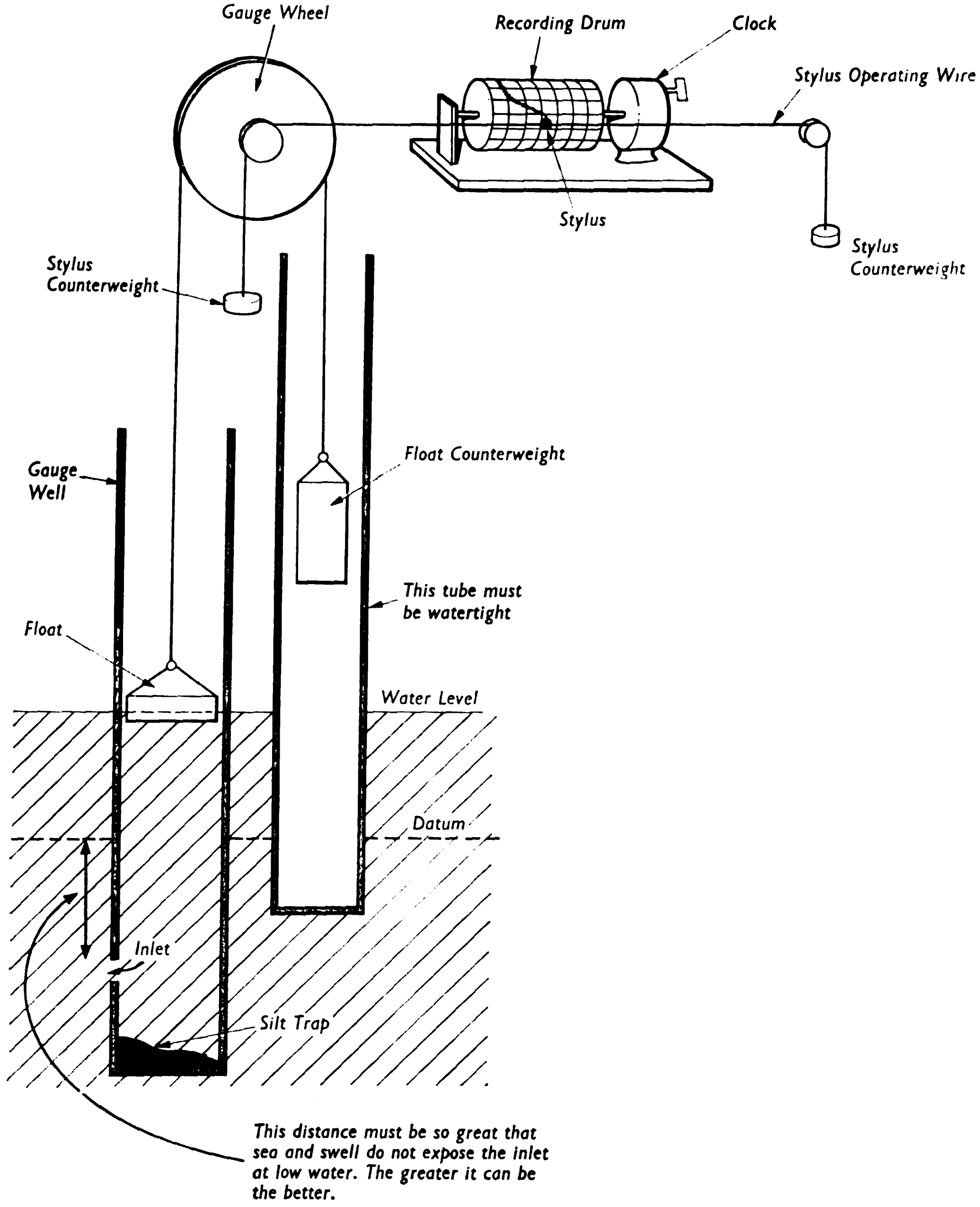

Fig. 2–22

to operate through a system of pulleys; this, however, has the disadvantage that it introduces additional friction.

The rotation of the gauge wheel is directly proportional to the rise and fall of the float. The figure shows how this rotation can be made to operate a stylus pen on the recorder drum by a simple system in which the pen is driven by a thin wire led over pulley wheels and controlled by counterpoised weights. Usually, however, the gauge wheel drives a train of gears which in turn drives the pen.

The recording drum is driven by the clock mechanism through a clutch. It is usually designed so that it can be removed to enable the recorder paper to be fitted; the clutch is necessary to enable the drum to be set to the correct time.

This type of gauge is normally very accurate and reliable. The long and cumbersome well, which must be truly vertical for accurate results, needs a supporting structure, and is therefore not easily transportable. It is, however, ideally suited as a permanent gauge for a storm warning organisation or in a port; its value will be enhanced if it operates a remote recorder which can be fitted some distance from the gauge itself in an office or traffic control room.

(ii) Pressure sensitive automatic tide gauges. A pressure sensitive tide gauge measures the pressure of the water above its sensitive head, which must be placed a few feet below sounding datum. The pressure experienced by the head is transmitted along a flexible pipe to a pressure measuring device, normally a Bourdon tube, which is calibrated in feet (one foot of water equals 0·45 lb/in.^{2} approximately) and made to operate the pen on a recorder.

A Bourdon tube consists of a short length of thin metal tubing, elliptical in cross section, bent into the arc of a circle. One end of the tube is closed, while the other is open to the pressure to be measured. The open end is fixed and the closed end connected to a system of links which magnifies and transmits its movement to the recorder pen. When pressure is admitted to the tube, it tries to become circular in cross section and uncurls slightly, thus moving the link mechanism.

Early pressure sensitive gauges were rather temperamental and unreliable, and therefore were not often used. Improvements in design and materials, especially in the pressure transmitting tube, have increased their reliability. They are becoming increasingly popular in hydrographic work since they can be made very portable; the pressure head and transmitting tube are much more easily managed than the cumbersome well and counterweight mechanism of a float gauge. Another great advantage is that the pressure transmitting tube need not be vertical. On an open beach it may be run out from the recorder situated above the high water line to the pressure head secured to a sinker on the sea-bed, below the level of datum. Alternatively, the pressure head may be secured to the end of a pole, which may be lowered to the correct depth at any angle and lashed in place. The comparison tide pole should not be used for this purpose since the pressure head may well have to be recovered for cleaning, repair or replacement.

Pressure operated tide gauges usually have either diaphragm or 'bubbler' pressure heads. The two varieties are described separately below.

(iii) Diaphragm pressure tide gauges. The diaphragm pressure head consists of a sensitive diaphragm or partially inflated bladder* enclosed in a metal box or cylinder, which is perforated so that water may enter freely. It is connected by a fine bore flexible tube to the Bourdon tube in the recorder. The volume of the air in this tube must be very small compared with that in the sensitive element; in addition the walls of the tube must be rigid or inelastic if the effective point of measurement is always to coincide with the pressure head.

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* It is important that the initial pressure inside the bladder in lb/in^2 should not be greater than one-third the depth in feet of the pressure head below datum. If it is, low water readings may be recorded inaccurately.

To damp the movement of the recording mechanism when the pressure head is subjected to rapid changes of pressure caused by sea or swell, a 'strangler' is normally fitted into the transmitting tube near the recorder. This consists of a metal bush into which a small bore spiral tube is fitted.

The flexible tube should be handled carefully, especially where there are joints. It is important to ensure that the pressure head does not become embedded in mud or soft sand, as this may prevent the water reaching the diaphragm.

(iv) 'Bubbler' or gas purge tide gauges. The pressure head of a 'bubbler' tide gauge consists simply of the open end of the pressure transmitting tube. The tubing need not have a particularly small bore nor be of special construction provided it is not easily crushed; nylon tubing with walls less than a millimetre thick and an internal bore of about five millimetres is normally used.

Fig. 2–23 illustrates a bubbler tide gauge. A continuous air supply, which is provided by a compressed air cylinder charged to about 1,800 lb/in.^{2}, is controlled by a reducing valve so that the working pressure of the instrument is anything up to about 40 lb/in.^{2}. The limiting pressure for any particular instrument must never be exceeded. The pressure head must never be placed so deep that the pressure at the highest possible high water exceeds the limiting pressure (one foot of water equals 0·45 lb/in.^{2} approximately). Gauges on both sides of the reducing valve indicate the pressures on the high and low pressure sides of the system; the cylinder should be replaced before the high pressure gauge shows zero.

The low pressure air is led through the flow control valve* to a bubble chamber containing water, and from there along the transmitting tube to the pressure head, which must be secured firmly so that it cannot move, especially vertically, at a depth a few feet below sounding datum. So long as air bubbles out of the open end of the transmitting tube, the whole low pressure system will have a pressure equal to that of the water at the open end. Changes in tidal height will therefore cause the pressure in this system to vary. If the highest pressure available at the reducing valve ever falls below the water pressure at the open end of the transmitting tube, the flow of air will cease, and a false reading will be obtained. In practice this is most likely to occur just before the high pressure cylinder becomes completely discharged.

The bubble chamber and the flow control valve together enable the user to see that the flow of air is maintained, and to control it so that it is sufficient to operate the instrument correctly, but not so great as to waste compressed air. The flow control valve should be adjusted so that air passes through the bubble chamber at the rate of about one bubble per second; it should maintain a steady flow despite changes in pressure caused by a rising or falling tide. A typical gauge will run for four or five weeks off one compressed air cylinder, provided the latter is maintained properly and does not leak.

A Bourdon tube is connected to the low pressure system. Its free end operates a recording arm on the end of which is a stylus pen. The pen marks a revolving drum in the normal way, automatically recording changing pressure and therefore tidal height.

Note that weed growth is stimulated by the air continuously bubbling through the end of the tube. After a few weeks' continuous operation, weed may be found growing two to three feet up the inside of the tube; it may after a while affect the flow of air.

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* This valve is designed so that it maintains a steady flow of air, regardless of changes in pressure in the transmitting tube.

BUBBLER TIDE-GAUGE

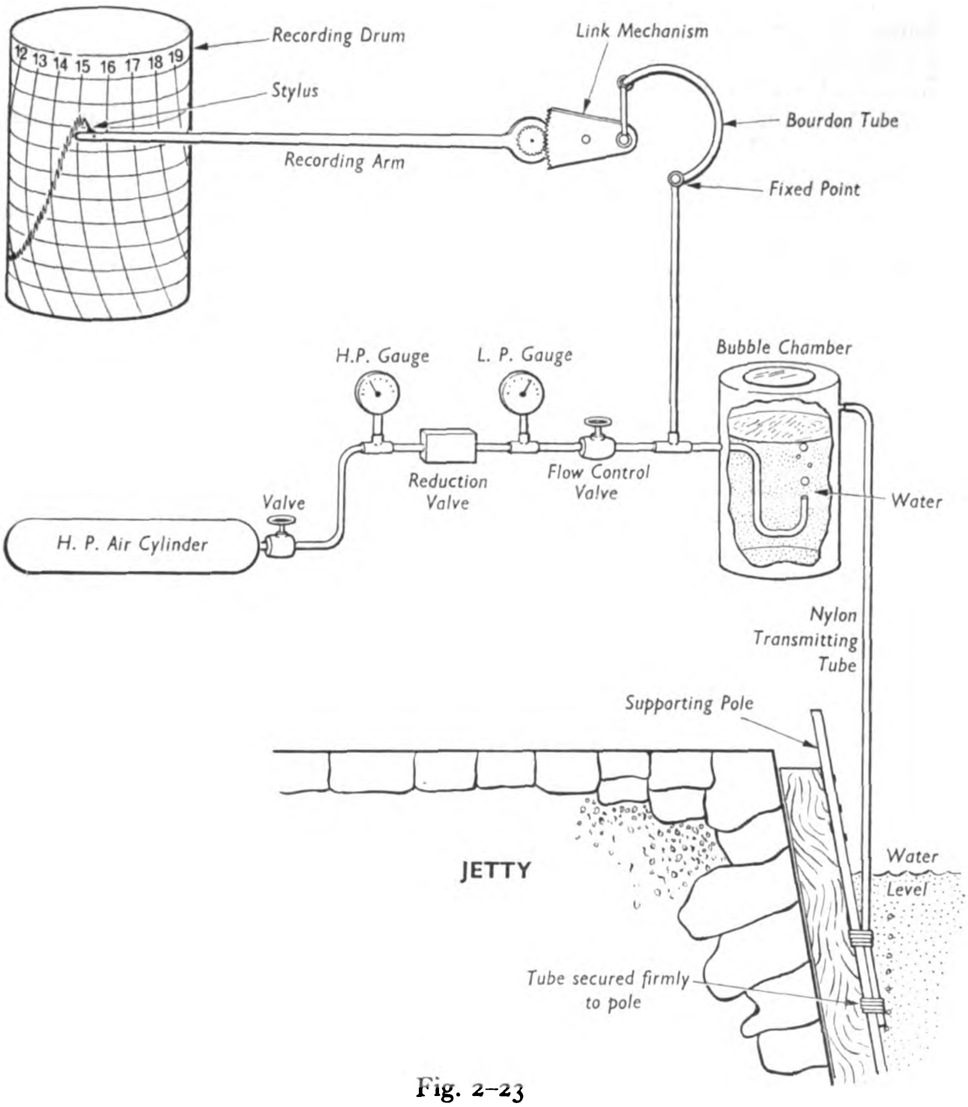

Fig. 2–23

(v) Calibration of a pressure tide gauge. A pressure tide gauge measures changes in water pressure at a fixed level. Water pressure is, however, dependent not only on depth but also on the density of the water.

Some pressure tide gauges are designed to operate correctly in water of a certain density, while in others adjustments can be made to the levers in the pen mechanism to allow for change in density. In any one place the density of the water is not likely to alter sufficiently to make any appreciable differences to the heights recorded.*

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* In an extreme case where salt water is replaced by fresh the density will decrease by three parts in 100 approximately.

The water at different places may, however, differ consderably in density. Therefore all types of pressure tide gauge must be calibrated whenever they are set up at a new site.

Calibration (and any adjustments, if possible) may be carried out aboard ship, before the gauge is landed; the position chosen should be close to the intended site for the gauge so that the water density will not be appreciably different. It should be carried out in calm conditions, in the following manner:

(*a*) Assemble the gauge and secure the pressure head to a weighted and marked lowering line, e.g. a leadline.
(*b*) Set the recording pen to zero.
(*c*) Lower the pressure head to a set depth close below the surface. If the gauge is a bubbler, start it in the manner described in (**iv**) above.
(*d*) Make a note of the recorded value on the recorder and the actual depth of the pressure head.
(*e*) Lower the pressure head to a depth a little more than the spring range of the tide below the setting in (*c*), and note the recorded value and the actual depth.
(*f*) Obtain similar observations at depth intervals of two or three feet, both whilst raising and lowering the gauge.
(*g*) Plot on graph paper true depths against the readings of the tide gauge. The curve should be a straight line passing through zero and will give the true tidal height above the pressure head for any tide gauge reading.*

The calibration can also be made after the tide gauge has been set up by comparing tide gauge readings against tide pole readings. Comparisons should be made over the whole range of the tide.

(vi) Notes on operating automatic tide gauges. Before an automatic gauge is set to work, its clock should be checked carefully, and adjusted if necessary so that its rate does not exceed one or two minutes per day.

Most automatic tide gauges will not run without attention for more than a week, and therefore must be visited at least weekly. It is, however, desirable to visit a gauge daily, to see that it is working correctly and to check its time and height records. A check sheet,† recording all daily and weekly checks and any other items of interest, should accompany all automatic tide gauge records; the following may be recorded on it:

DAILY

(*a*) Daily checks, which are best shown in columns, giving the date, correct time, time on the graph, height of tide on comparison tide pole and height of tide on graph.
(*b*) Remarks, including the state of the sea, weather and defects found in the instrument.

WEEKLY

(*c*) Place.
(*d*) Time kept (B.S.T., G.M.T., etc.).
(*e*) Date and time of starting record.
(*f*) Date and time of removing record.

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* A defective or badly designed gauge may suffer from hysteresis effects, and will then produce different readings, depending on whether it is being raised or lowered. In this case it will be imperative to calibrate the gauge against a tide pole, in its operating position.

† Form *H 516*, *Summary of Checks on Automatic Tide Gauge*, is published by the Hydrographer of the Navy, and may be obtained from him.

On a weekly visit to an automatic tide gauge, the following points should be attended to:

(1) Check the tide gauge clock time and height as for a daily check.

(2) With a bubbler tide gauge, check the air pressure in the cylinder and the flow of air in the bubble chamber. Renew the air cylinder if necessary.

(3) Complete all details on the check sheet.

(4) Remove the completed record from the drum and attach it to the check sheet.

(5) If the clock is not electric, wind it fully.

(6) Fill the pen nib with the special ink provided. If necessary the pen may be cleaned with methylated spirits.

(7) Annotate a new sheet of graph record paper and fit it to the drum. Make sure that it is correctly fitted; the bottom edge must touch the flange round the end of the drum and all graduations must be in line across the overlap.

(8) Set the drum to the correct time against the pen, making certain that its last movement is against its normal direction of motion so as to eliminate backlash.

(9) Read and note the heights of tide given by the comparison tide pole and the recorder.

(10) Compare the values of time and height in (8) and (9) above with the time and height at the end of the old record, as a check against gross errors.

(11) Start a new check sheet.

(12) About five minutes after (8) above, compare time and height as given by the recorder with their true values, to make quite certain that all is well.

(13) Enter details on the check sheet. Do not reset the pen, unless the discrepancies are large, i.e. more than about 0·5 feet or 10 minutes. If the pen *is* reset, repeat (12) five minutes later.

(14) If the tide gauge is float actuated and the sea is calm, check the water levels inside and outside the well. This check is best carried out at about half tide when the tidal levels are altering most rapidly; there will be very little point in making it at high or low water.

d. Automatic sea-bed tide gauges

An automatic sea-bed tide gauge depends on the sea-bed for its basic reference plane. To be of any practical use to the hydrographic surveyor it must supply tidal information at least as accurate as, and with greater convenience than the methods discussed above.

Up to the present time (1966) no really satisfactory gauge of this type has been produced. There is no reason in theory why one should not be, but the practical difficulties and a lack of demand have made research and progress slow.

The following notes set out the basic requirements, and may encourage the growth of new ideas:

(i) Basic requirements.

(*a*) An automatic sea-bed tide gauge must be completely self contained, and designed so that it will work unattended for at least seven and preferably 14 days.

(*b*) The record which it makes must indicate time to the nearest two minutes, and the height of the tide to within 0·1 feet.

(*c*) If the gauge can be made to transmit its readings to a ship some distance off, when these are required, so much the better. These transmissions might be made by radio, or by sonic methods through the water. A gauge which could not transmit its readings would still be useful, though it would not provide a very convenient service to a ship which was sounding.

(*d*) It will be a great advantage if the gauge record can be changed whilst the gauge is in its working position.

(*e*) The gauge itself must be reasonably easy to lay and recover, particularly if the requirement in (*d*) above cannot be met.

(*f*) It must be possible to calibrate the gauge at any time, without having to lay it to do so.

(*g*) If any sensitive part of the instrument is laid on or near the bottom, it must be arranged that the recorded readings cannot be affected by accumulations of sand or mud around or over it. It may well be prudent to arrange that sensitive elements are supported several feet clear of the bottom.

(ii) Pressure sensitivity sea-bed tide gauges. A pressure sensitive gauge similar to those described in Section **8c(ii)** above could be designed to operate as a sea-bed gauge. The diaphragm or pressure head would have to be supported at a fixed height relative to the bottom, in such a way that it could not become silted up. It might well be incorporated into the mooring of a small buoy, which could then be made to hold the recording device and transmitting equipment. The pressure transmission tube could either form the mooring itself or be fitted inside an orthodox mooring. If possible the pressure measuring element (e.g. Bourdon tube) of such an instrument should be exposed to the atmosphere.

Some existing sea-bed gauges are designed to be laid as one unit on the sea-bed, and are fitted with a marker buoy simply to aid their recovery. Besides being inconvenient to operate (the gauge must be recovered from the sea-bed to obtain its readings) these gauges cannot measure the true rise and fall of the water, since they are not open to the atmosphere. An increase in barometric pressure of one inch of mercury will depress the surface of the water by about one foot; however, the pressure at the sea-bed will remain constant, since the changes in barometric and water pressures there will be equal and opposite. For this reason readings obtained from sealed gauges laid on the sea-bed must always be corrected for changes in barometric pressure.* Where the pressure measuring element is exposed to the atmosphere these corrections will not be necessary.

(iii) Sonic sea-bed tide gauges. If an instrument similar to an echo sounder were fitted inside a small buoy, which was laid with a very tight moor over a flat bottom, it could be made to record the rise and fall of the tide at suitable intervals. Alternatively the transducers could be built into the buoy's anchor or sinker, so that they faced vertically upwards, and obtained echoes from the surface of the water; the recorder could be fitted in the buoy, and the electric cables run inside the mooring wire. In this case it would not be necessary to have either a flat bottom or a taut moor.

It would be necessary for a tide gauge of this type to be fitted with a very stable time measuring device, to ensure that changes in its equivalent sounding velocity did not become large enough to introduce significant errors into the recorded height of the tide (see Chapter 3, Section 4).

9. Tidal Observations

a. Observations on tide poles; field checks

The surveyor should read his tide pole or gauge to the nearest tenth of a foot. Over the high and low water periods recordings should be obtained every 10 minutes or so, in order to established the exact shape of the tidal curve around these times; this is particularly important when observations are being taken for analysis, or to transfer datum. At other times readings obtained at half hourly intervals should be adequate. Times should be noted to the nearest minute; a reading may quite safely be taken a few minutes early or late, provided the temptation to book it at the exact half hour is firmly resisted.

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* One inch of mercury is equal to about 13½ inches of sea water.

(i) Reading a tide pole; sea, swell and breakers. If the sea is calm a tide watcher should have no difficulty in estimating the height of tide on his pole to the nearest tenth of a foot. He should check his watch (which should be a good one) daily, and make a note of its error. He should also make quite sure every day that the tide pole has not moved in a vertical plane. If the pole is secured to some form of natural or man-made object, he may note that a line scribed against one of the pole graduations has not moved relative to the pole, or that the top of the pole is still the correct distance below a reference mark. If the pole is erected off an open beach he should insert a stake at a convenient point (above high water if possible), make quite certain that it cannot move and then proceed as follows:

(*a*) Place his eye close to, and at the same level as, the top of the stake, and note the reading on the pole where the sea horizon intersects it; it may be necessary to use binoculars. This should be done as soon as the pole has been levelled.

(*b*) Repeat this test once a day, preferably when the height of tide is about the same as it was on the first occasion. The reading should remain constant, or very nearly so.*

This test is very sensitive indeed, if it is applied properly.

If there is any sea or swell, it will not be easy to estimate the mean level of the water accurately. The following procedure is recommended:

(1) Watch only the tops of the crests on the pole, and note mentally the heights reached by six or 10 which pass in succession. Mean these heights and write down the mean.

(2) Do the same for an equal number of troughs, as they pass in succession.

Then the height of tide required is the mean of the means obtained in (1) and (2). Each complete set of readings should be obtained quickly, and certainly within one minute.

If the tide pole is in breakers the same procedure may be used, but the fact should be especially noted, since the mean level of the breakers will probably not coincide with that of the undisturbed water to seaward of them.

(ii) Reading a tide pole which is not vertical; corrections. If a tide pole is not vertical, all readings of the water level taken from it will be greater than they ought to be.

Fig. 2–24(*a*) shows a pole which has been set up truly vertical. On it sounding datum has been found by levelling to be 2·6 feet, and at the instant of observation the water level is at 7·6 feet.

In Fig. 2–24(*b*) the same pole has tilted over at an angle θ to the vertical, and all apparent heights read off it (including that of sounding datum) are greater than they ought to be. A reading taken on pole (*b*) must be multiplied by $\cos \theta$ to convert it to pole (*a*). If, in the figure, the tide falls to an apparent level of 2·7 feet on pole (*b*), it will in fact be at sounding datum (2·6 feet on pole (*a*)).

Now suppose that pole (*b*) has been relevelled, and that the value of sounding datum on it is (*d*). Then the true height of the tide above sounding datum is given by the formula:

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* If observations are made at different states of the tide, a varying dip will affect the results. Errors should be very small provided the pole is reasonably close to the observer, and the tidal range is not too great.

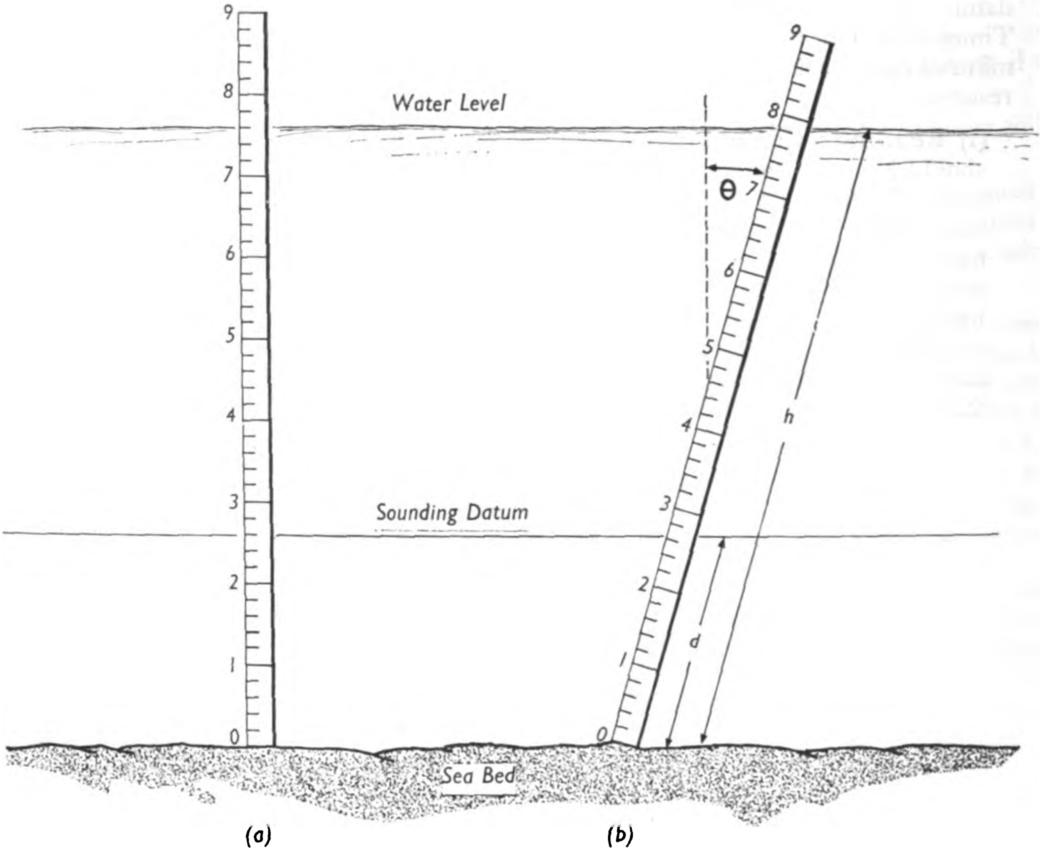

Fig. 2–24

True tidal height above datum = $(h-d)\cos\theta$
where h is the apparent height on the pole.

Note that in the figure the zero of both poles lies on the sea-bed. If a pole has an extension piece below the zero of its graduations, then the length of this piece must be allowed for when making the corrections referred to above.

If a tide pole takes on a tilt after it has been erected and levelled to, it should of course be relevelled immediately, since it may well have moved up or down in the act of tilting.

Poles which are not vertical introduce complications into the calculation of tidal reductions; more important perhaps, they tend of their very nature to be unstable, and sooner or later to let the surveyor down. They should, therefore, never be tolerated, except in exceptional circumstances. Time spent in erecting a pole truly vertical, and making certain that it will remain vertical, will never be wasted.

(iii) Field checks on tidal observations; observation of half tide rocks. If the instructions given in Section **6** of this chapter have been applied correctly, the surveyor should obtain sufficient information from his tide poles to enable him to calculate accurate reductions for his soundings.

Even so, he should never lose an opportunity to check that all is, in fact, as it should be.

As soon as he starts to sound, either in the ship or the boats, he should look out for rocks, wrecks, sandbanks and other objects which are just being covered or uncovered by the tide. By noting the time he will be able to calculate their drying heights. He should make a note of these drying heights, and thereafter observe the same objects as they are awash as often as possible. If the objects dry at about half tide, so much the better.

If all is well with his arrangements for observing the tides, each object will be awash at a constant height of tide, regardless of whether the tide is rising or falling, and on which pole it was observed. Inadequate tidal observations will almost certainly cause an object (particularly if it is a half tide rock) to be awash at apparently different heights of tide.

These field checks are particularly suited to the detection of incorrect time differences and changing diurnal and shallow water effects. Suppose, for instance, that the tide at a particular place is 10 minutes earlier than the surveyor thinks. Then a half tide rock will be covered too early on a rising tide (and the reduction applied will be too small), and it will uncover too early again on a falling tide (and the reduction applied will be too great). Changes in the shape of the tidal curve from place to place may be detected in the same way.

It is important to note that the errors referred to above may well be present even when the transfer of sounding datum has been made perfectly properly.

b. Tidal records

Tidal records may be subdivided into two types—those made in the field, and those which are forwarded into office for permanent custody. They are discussed separately below.

(i) Tidal records in the field. If observations are being made on a tide pole, the following information should be entered daily in the field record, in addition to the apparent times and heights of the tide:

(*a*) The time being kept, and the error of the watch. Times should *not* be corrected mentally for watch error before being entered.

(*b*) Whether or not the pole is upright. If it is not the time and cause of its movement should be noted.

(*c*) That the pole has not moved up or down. (See Section **9a(i)** for the procedure for checking this.)

(*d*) If the pole is not upright, and this fact is accepted, its angle of tilt should be noted. Apparent readings should be entered in the record; the corrected readings may then be added alongside them later on.

(*e*) The state of the weather, and the sea and swell conditions. If these change during the day, the fact should be noted, since the reliability of the observations will probably be affected.

Section **8c(vi)** of this chapter sets out the field records which should be kept if an automatic tide gauge is being used.

(ii) Permanent tidal records. The field records referred to above should be carefully checked on board, and kept until the permanent records, which are compiled from them, have been declared to be satisfactory by the authority to whom the surveyor is responsible.

Permanent records should contain the following information:

(*a*) The times and heights of the tide above the zero of the pole or gauge used. Times observed by watch should be corrected zone times. Automatic gauge records must always be forwarded as part of the permanent records. They must state clearly what time and height corrections are to be applied to their apparent readings. Details of all calibrations and field checks should also accompany gauge records.

(*b*) The state of the weather, and sea and swell conditions, particularly when these change.

(*c*) The height of sounding or chart datum above the zero of the pole or gauge.

(*d*) Details of how sounding or chart datum was obtained; these should include all calculations.

(*e*) A description of the tide pole or gauge site. A photograph should be obtained if possible. Where an automatic gauge has been used the comparison tide pole site should also be described.

(*f*) Full details of all the benchmarks to which the tide pole or gauge has been levelled. Photographs should be included if possible.

(*g*) A brief description of the levelling itself, and a list of the heights of the various benchmarks above the zero of the pole or gauge, and sounding datum.

If in doubt the surveyor should include too much in the records which he forwards to the office, rather than too little.

(iii) Records of levelling to a tide pole. Although the height of the tide can only be read to the nearest tenth of a foot on a tide pole or gauge, all levelling should be carried out to the nearest hundredth of a foot.

This degree of precision is required for the following reasons:

(*a*) Mean sea level, which is the mean of very many hourly observations, may be calculated with an accuracy far greater than that of a single observations.* It is of great importance to land engineers, as well as to seamen and surveyors.

(*b*) Datum may well be transferred from pole to pole along a long stretch of coast. The poles may be dismantled and re-erected whilst this is being done, and the whole process may take some time. Therefore the precision of the various levelling operations must be far greater than that of the tidal readings, if systematic errors are to be avoided.

Instructions for levelling a tide pole are given in Volume 1, Chapter 9, Section 8.

c. Producing a tidal reduction curve when a co-tidal chart has been used

The construction of a tidal reduction curve from unadjusted observations made on a tide pole or gauge is described in Chapter 3, Section 29.

If a co-tidal chart is being used, both the ratio of ranges and the time differences which must be applied to the tide pole readings will vary as the ship moves about during the course of a day's sounding, and the construction of a tidal reduction curve for her will be made more difficult.

Two basic points must be considered:

(1) If an incorrect ratio of ranges is used, sounding datum for the area in question will be wrong. However, since it is permissible to change sounding datum in one foot steps, a fixed ratio may be used over quite a large area, which will be greater as the range of the tide becomes less. Suppose, for instance, that the range of the tide at the standard pole is 20 feet, and that in the survey are the ratios of ranges vary between 0·8 and 0·5. What will be the magnitude of the steps by which the ratio may be changed, if sounding datum is to vary in steps not greater than one foot?

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* In theory, the mean of 100 observations, each taken to the nearest 0·1 foot, should be accurate to within 0·005 feet.

Assume that at the pole the low water in question falls to datum (it makes no difference to the validity of the argument if it does not), and that the high water is 20 feet. Then the following table sets out the heights of high water, low water and mean tide level above the correct datums at various places.

	AT THE TIDE POLE	ALONG THE 0·8 RATIO LINE	ALONG THE 0·7 RATIO LINE	ALONG THE 0·6 RATIO LINE
H.W.	20 feet	16 feet	14 feet	12 feet
M.T.L.	10 feet	8 feet	7 feet	6 feet
L.W.	0	0	0	0

Since M.T.L. is a fixed level in the survey area, it can be seen that datum will change in one foot steps if the ratio is varied in steps of 0·1. Therefore, between the 0·8 and 0·7 ratio lines a constant factor of 0·75 may be used; this should be changed to 0·65 between the 0·7 and 0·6 ratio lines, and so on. The greater the range the smaller will the steps of change in ratio have to be.

(2) If an incorrect time difference is used, it will introduce errors into the reduction curve even when the datum employed is correct. These errors may not be very great around the times of high and low water, where the tidal curve is flat; but they will nearly always be significant, and may on occasions be very considerable at half tide, when the curve is rising or falling steeply. Once again the errors depend on the range, being largest when it is great.

When confronted by a problem of this sort the surveyor must use his judgement and common sense. He may be able to select areas in which fixed time differences and ratios may safely be applied. If in doubt he should use the method described below, which will produce an accurate reduction curve in any circumstances, provided that the basic co-tidal information is correct.

(i) Constructing a co-tidal reduction curve for a moving vessel. Fig. 2–25(*a*) shows part of a co-tidal chart, on which the ship's track has been plotted. The ship happens to be moving very fast indeed for the purposes of this explanation; in practice no vessel is likely to encounter such marked changes of ratio and time difference in

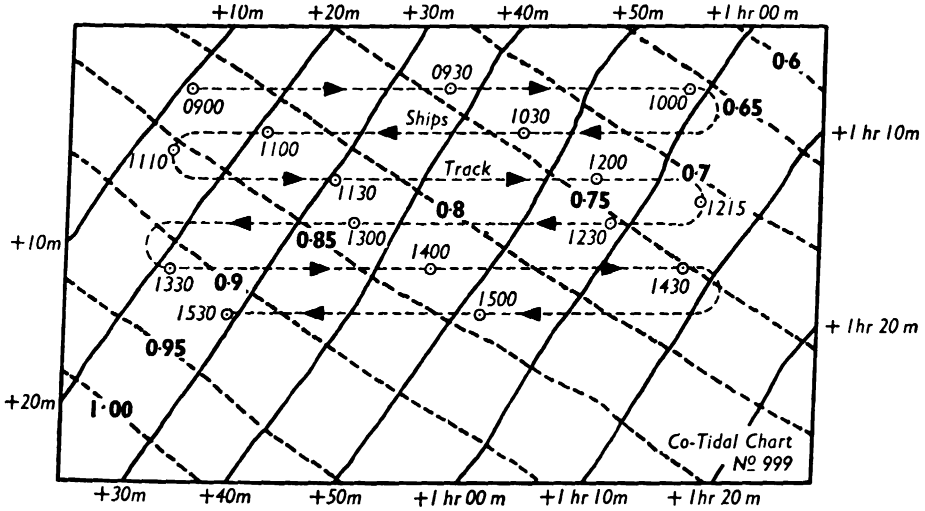

Fig. 2–25a

such short periods.* It is required to find what tidal reductions apply to the ship's changing position.

The procedure is as follows:

(*a*) Observe the tide in the usual way on the standard pole, and draw the tidal curve. It is shown as a pecked line in Fig. 2–25(*b*).

(*b*) Make a form similar to that shown below:

REDUCTIONS FOR A MOVING VESSEL

1 TIME AT SHIP	2 TIME DIFFERENCE	3 RATIO OF RANGES	4 TIME AT POLE (COL 1– COL. 2)	5 HEIGHT AT POLE AT TIME IN COL. 4 (FROM CURVE)	6 HEIGHT FOR SHIP'S REDUCTION CURVE (COL. 3 × COL 5)	7 TIME AT SHIP
	hr min			*feet*	*feet*	
0900	+ 0 11	0·82	0849	10·8	8·8	0900
0930	+ 37	0·74	0853	11·0	8·1	0930
1000	+ 58	0·66	0902	11·4	7·5	1000
1030	+ 47	0·74	0943	13·4	9·9	1030
1100	+ 22	0·82	1038	15·4	12·6	1100
1110	+ 13	0·86	1057	15·6	13·4	1110
1130	+ 31	0·82	1059	15·6	12·8	1130
1200	+ 55	0·73	1105	15·6	11·4	1200
1215	+ 1 05	0·72	1110	15·5	11·2	1215
1230	+ 58	0·76	1132	15·2	11·5	1230
1300	+ 35	0·83	1225	13·2	11·0	1300
1330	+ 22	0·92	1308	10·8	9·9	1330
1400	+ 45	0·83	1315	10·6	8·8	1400
1430	+ 1 08	0·75	1322	10·2	7·6	1430
1500	+ 52	0·83	1408	8·0	6·6	1500
1530	+ 29	0·92	1501	5·9	5·4	1530

and:

(i) In column 1 enter the times at which tidal heights at the ship are required. In this case they are at half hourly intervals between 0900 and 1530.

(ii) In column 2 enter time differences taken from the co-tidal charts for the various positions of the ship at the times listed in column 1.

(iii) In column 3 enter ratios obtained in a similar way from the co-tidal chart.

(iv) Subtract the time differences in column 2 from the times in column 1 to obtain equivalent times at the pole; enter these in column 4. Watch the signs and use common sense. In this case the tide at the ship is later than that at the pole.

(v) From the tidal curve for the pole (Fig. 2–25(*b*)) read off heights for the times listed in column 4; enter these in column 5.

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* Helicopters and hovercraft might well, however, meet conditions very similar to those described here, if they were sounding.

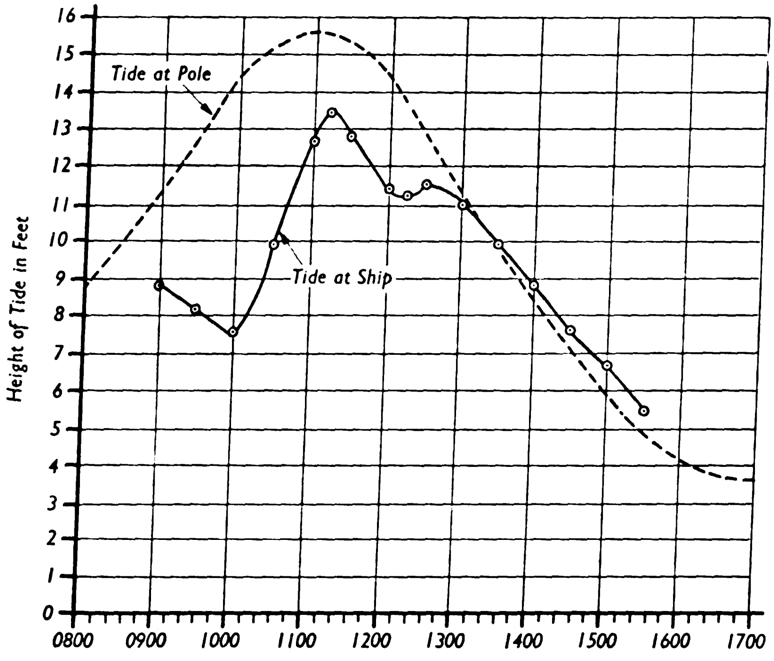

Fig. 2–25b

(vi) Multiply the heights in column 5 by the ratios in column 3 to obtain the heights of tide at the ship. Then plot the ship's reduction curve; it is shown as a firm line in Fig. 2–25(*b*)).

Note that in this case additional points have been plotted for 1110 and 1215, when, owing to the ship's reversal of course, her reduction curve is anything but regular.

It can be seen in Fig. 2–25(*b*) that the ship's reduction curve bears very little resemblance to the curve at the tide pole, or indeed to any normal curve of tidal movement. It has, of course, been exaggerated for this example. However, similar types of curve may be experienced in practice, particularly if the ship is moving fast; the prudent surveyor will, therefore, always make certain just what is going on, if he is using a co-tidal chart to obtain reductions for his soundings.

10. Harmonic Analysis and its Application to Tides

Any wave form which repeats itself may be represented by the sum of a number of pure sine or cosine waves whose wavelengths (and frequencies) all bear a simple harmonic relationship one to another. The period of the fundamental waveform will be the repetition period and the wavelength of each harmonic will be one half, one third or one quarter that of the fundamental and so on; it will always be a simple fraction. Fig. 2–26 shows a complex curve (turned sideways it will be seen to be a face in profile) which repeats itself every l units measured along the x axis. The fundamental wavelength of this curve is l; its fundamental frequency is proportional to $1/l$. It could be built up by adding together a great many pure sine waves of wavelength l, $l/2$, $l/3$, $l/4$ and so on. The greater the number of harmonics used the more nearly would their sum represent the original curve exactly. This process of breaking down a complex curve which repeats itself into a number of pure sine or cosine* curves whose wavelengths are all related by integral numbers or fractions (e.g. 2,

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* Note that a cosine curve is merely a sine curve which has been shifted in phase through 90°, i.e. $\cos\theta = \sin(90° - \theta)$.

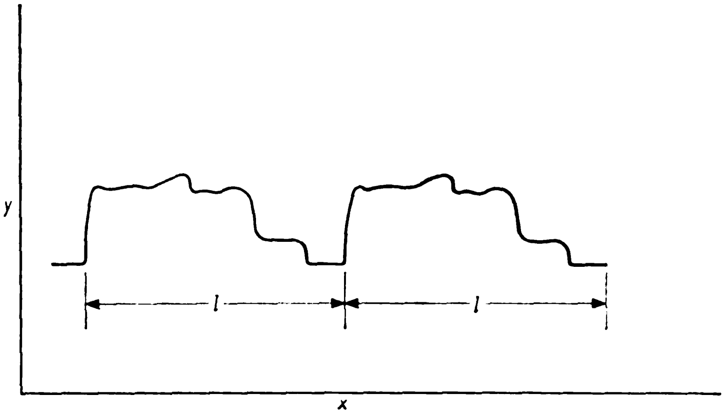

Fig. 2–26

1, ½, ⅓, etc.) constitutes harmonic analysis in one of its simpler forms. It may be carried out to any desired standard of accuracy, merely by adding to the number of harmonics employed. It is often used in radio work, in acoustics and in many other scientific fields. It will only work satisfactorily when the curve to be analysed repeats itself faithfully after a fixed interval.

Suppose now that the curve to be analysed never repeats itself exactly. The methods of harmonic analysis may still be used, but there will now be no fundamental and no simply related harmonics. The curve may be represented as the sum of a number of pure sine or cosine waves, whose wavelengths and frequencies bear no simple relationship to each other. Wavelengths might well, for instance, be l, 0·979l, 0·713l and so on. This more complex form of harmonic analysis is the one which has to be used in the case of tides, since so far as is known no tidal curve ever repeats itself exactly.

In what follows the simpler form of harmonic analysis, which will split up a curve which repeats itself, will be discussed first. The way in which the basic principles of this simple from of analysis are applied to the analysis of tidal movement will then be described.

a. Simple harmonic analysis; basic principles

Fig. 2–27(*a*) shows a wave form with a period of 24 hours exactly. It is not a tidal curve, for it repeats itself faithfully every day, and its period of 24 hours is shorter than that of a typical 'diurnal' tide. However, it has been especially chosen for certain similarities which it has with tidal curves.

This wave form has in fact been produced by adding together the cosine curves shown in Figs. 2–27(*b*), (*c*) and (*d*). The reader may, if he wishes, check this fact himself by adding values taken off the cosine curves; this may be done most conveniently with a pair of dividers.

Fig. 2–27(*b*) is a pure cosine curve with a period of 24 hours exactly and an amplitude* of four feet; its phase φ at 0 hours happens to be 030°. It is the fundamental in this case and is analogous to a diurnal tidal curve.† Fig. 2–27(*c*), also a pure cosine curve, has a period of 12 hours exactly, an amplitude of eight feet, and its phase φ at 0 hours happens to be 360°; its counterpart in tidal theory is the semi-diurnal tide. The curve in Fig. 2–27(*d*) is analogous to a quarter-diurnal tide; it has a period of six hours exactly, an amplitude of two feet, and its phase φ at 0 hours happens to be 060°.

Suppose now that the analyst is confronted with Fig. 2–27(*a*), and wishes to break it down into its component harmonic constituents. He knows that the fundamental has a period of 24 hours, since the curve repeats itself exactly in this time. He finds out

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* Note that in all tidal work amplitude equals semi-range, not range.

† In tidal work, however, the diurnal constituent is certainly not the fundamental.

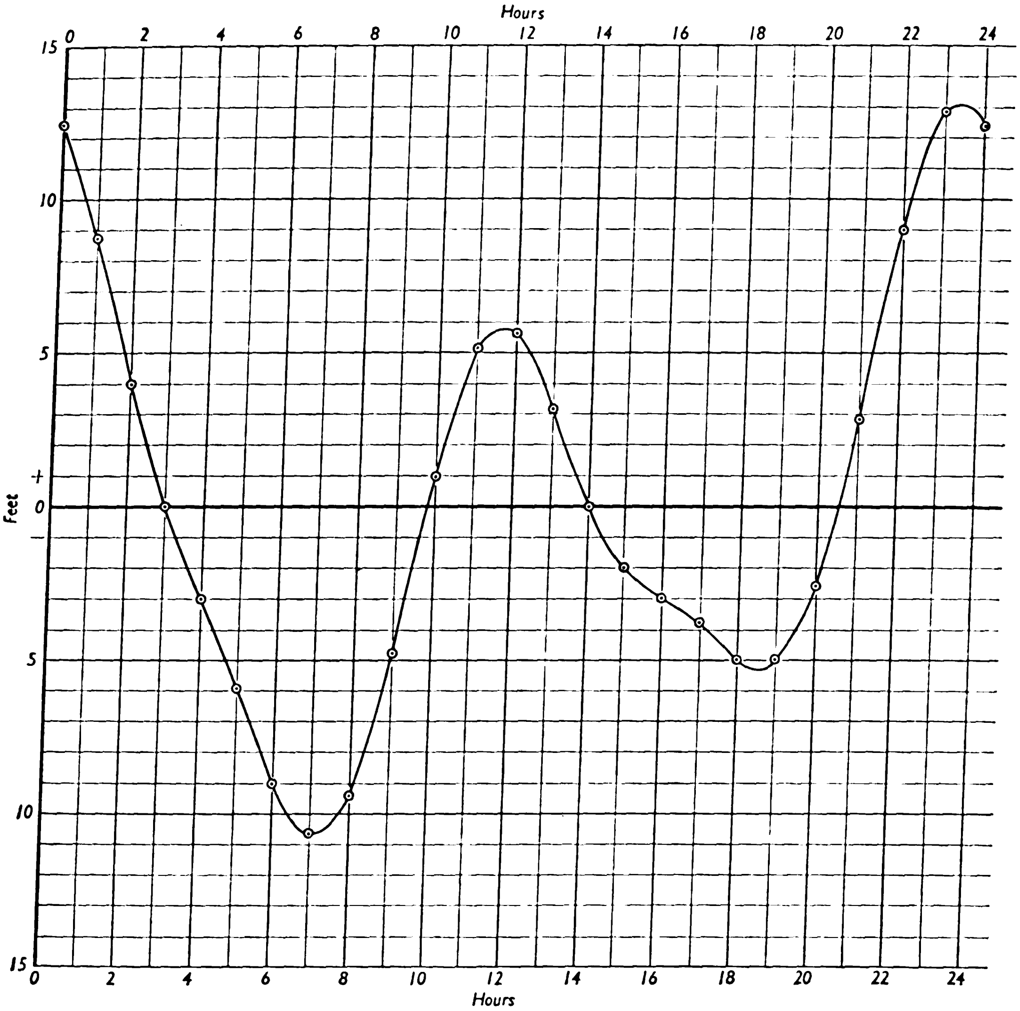

Fig. 2–27a

(or in the last event guesses) that semi-diurnal and quarter-diurnal constituents only are also present. He must discover the amplitude R and phase angle at 0 hours φ, for each of them; there are six unknown quantities in all. The problem could be solved graphically, but this would be laborious and not very precise, and it is better to use algebraic methods.

(i) The process of analysis; formulae and simultaneous equations. Suppose that for any cosine wave form:

Amplitude = R
Time in hours = t
Phase at time $(t = 0) = \varphi$.

Rate of change of phase in degrees per hour = n and height (+ above or − below the x axis)* = h.

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* In tidal work this x axis is Mean Sea Level; hence the importance of M.S.L.

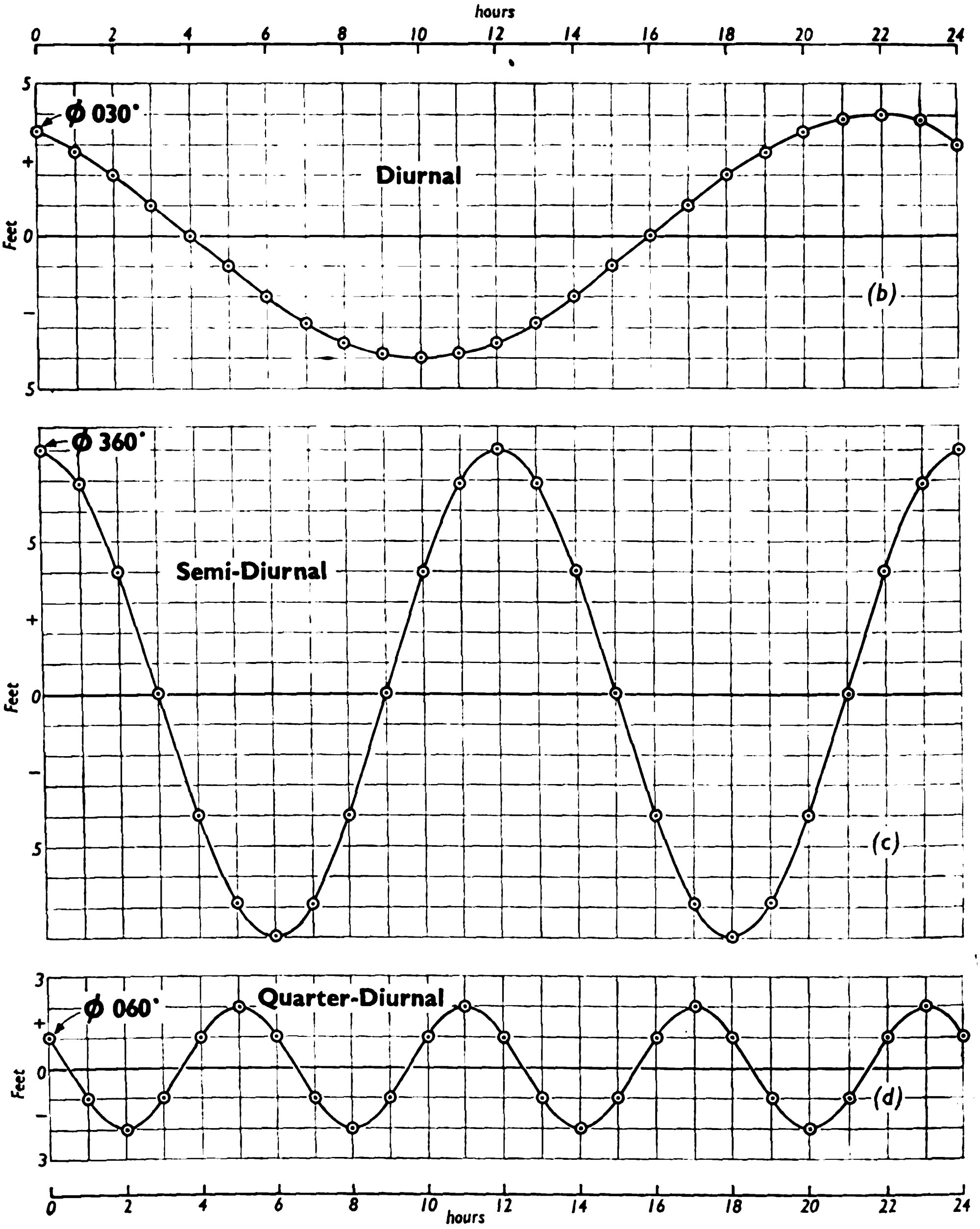

Fig. 2–27b, c, and d

Then at any time:

$$h = R\cos(\varphi + nt).$$

Note that nt is an angle; it is the increase in phase since a time $t = 0$, when the phase was equal to φ.

To be of use this simple formula must be expanded by the rule for the cosine of the sum of two angles. Thus:

$$\begin{aligned} h &= R\cos(\varphi + nt) \\ &= R\cos\varphi\cos nt - R\sin\varphi\sin nt. \end{aligned}$$

If $R\cos\varphi = A$ and $R\sin\varphi = B$, RAB is a right angled triangle with R as its hypotenuse and A and B as its other two sides. Then:

$$\tan\varphi = \frac{R\sin\varphi}{R\cos\varphi} = \frac{B}{A}$$
$$R = A/\cos\varphi = B/\sin\varphi$$
$$R^2 = A^2 + B^2$$

and $h = A\cos nt - B\sin nt$.

If A and B can be found, R and φ can be obtained from them.

For the diurnal curve in Fig. 2–27(*b*), this formula might be written

$$h_1 = A_1\cos n_1t - B_1\sin n_1t,$$

and since n_1 (for a diurnal curve) $= \frac{360^\circ}{24} = 15^\circ/\text{hour}$*

$$h_1 = A_1\cos 15^\circ t - B_1\sin 15^\circ t.$$

For a semi-diurnal wave form (Fig. 2–27(*c*)) the formula would be

$$\begin{aligned} h_2 &= A_2\cos n_2t - B_2\sin n_2t \\ &= A_2\cos 30^\circ t - B_2\sin 30^\circ t \end{aligned}$$

since $n_2 = \frac{360^\circ}{12} = 30^\circ/\text{hour}$.*

Again, for a quarter-diurnal waveform (Fig. 2–27(*d*)) the formula would be

$$h_4 = A_4\cos 60^\circ t - B_4\sin 60^\circ t$$

since $n_4 = \frac{360^\circ}{6} = 60^\circ/\text{hour}$.*

The complex curve in Fig. 2–27(*a*) consists of the sum of the three curves whose formulae are set out above.

Therefore, if H is the height of this curve above or below the *x* axis at time *t*,

$$\begin{aligned} H &= h_1 + h_2 + h_4 \\ &= A_1\cos 15^\circ t - B_1\sin 15^\circ t + A_2\cos 30^\circ t \\ &\quad - B_2\sin 30^\circ t + A_4\cos 60^\circ t - B_4\sin 60^\circ t. \end{aligned}$$

This last formula is fundamental to all harmonic analysis. For each harmonic constituent there will be two terms, $A\cos nt$ and $B\sin nt$; the analyst may use as many pairs as he wishes.

In this particular case there are six unknown quantities in the fundamental formula, three As and three Bs. To find them it will be necessary to have at least six values of H (taken from Fig. 2–26(*a*)) so that six simultaneous equations can be written.

---

* In tidal work these quantities are very often referred to as the speeds of the various harmonic constituents.

It will be better if values are taken off the curve every hour, to give 24 simultaneous equations, each of the type

$$\text{H (from Fig. 2–27}(a)) = A_1 \cos 15°t - B_1 \sin 15°t$$
$$+ A_2 \cos 30°t - B_2 \sin 30°t + A_4 \cos 60°t - B_4 \sin 60°t.$$

The problem then becomes one of how to solve 24 simultaneous equations, each with the same six unknown quantities. An equation may be multiplied by any number, without altering it in any way. Individual equations in a simultaneous set may be multiplied by different numbers without in any way altering the basic nature of the set. These individual equations may be added or subtracted from each other to form new and possibly simpler equations at the analyst's pleasure. In the table on page 65 this process of manipulation has been applied to values taken from Fig. 2–27(*a*).

Referring to the table, t in hours is given in column 1. Column 2 lists observed values of H for various times t, taken from Fig. 2–27(*a*); columns 3 and 4 tabulate $A_1 \cos 15°t$ and $B_1 \sin 15°t$ respectively. Columns 5 and 6 tabulate $A_2 \cos 30°t$ and $B_2 \sin 30°t$; columns 7 and 8 tabulate $A_4 \cos 60°t$ and $B_4 \sin 60°t$. In all these columns the numbers associated with the various letters are known as coefficients; thus, for $t = 13$ the coefficient of B_2 is $+0{\cdot}500$ ($\sin nt = \sin(13 \times 30°) = \sin 390° = +0{\cdot}500$).

Each horizontal line, from $t = 0$ to $t = 23$, represents one equation. Thus, for $t = 2$ the equation is

$$4{\cdot}00 = 0{\cdot}866A_1 - 0{\cdot}500B_1 + 0{\cdot}500A_2 - 0{\cdot}866B_2 - 0{\cdot}500A_4 - 0{\cdot}866B_4,$$

and for $t = 17$ the equation is

$$-3{\cdot}89 = -0{\cdot}259A_1 + 0{\cdot}966B_1 - 0{\cdot}866A_2 - 0{\cdot}500B_2 + 0{\cdot}500A_4 + 0{\cdot}866B_4.$$

Beside each column, under the asterisks, is a multiplier, either 1, 0 or −1. Note that it is the same for each horizontal line.

Now each simultaneous equation, represented by a horizontal line in the table, is multiplied by the multiplier concerned and then all 24 equations are added together.

The result, which is shown in tabular form at the bottom of the table and which may be checked by the reader, is as follows:

$$+83{\cdot}92 - 31{\cdot}32 = 15{\cdot}19A_1 - 0B_1 + 0A_2 - 0B_2 + 0A_4 - 0B_4.$$

The careful choice of the multipliers has eliminated every unknown except A_1 from the sum of the 24 equations. Therefore

$$15{\cdot}19A_1 = 52{\cdot}60 \text{ and } A_1 = 3{\cdot}46.$$

Different sets of multipliers may be used in turn to remove all but one of the unknowns from the sum of the 24 equations. Those that are applicable in this case (for $n = 15°$, 30° and 60°) are listed below. There are many others.*

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* If the coefficient of the unknown concerned, i.e. $\cos nt$ or $\sin nt$, is positive, the multiplier is +1; if it is negative, the multiplier is −1; if it is zero the multiplier also is zero.

EXTRACTING A_1 FROM 24 HOURLY OBSERVATIONS

1	2		3		4		5		6		7		8
			DIURNAL				SEMI-DIURNAL				QUARTER-DIURNAL		
TIME *t*	OBSERVED HEIGHT H	•	$A_1 \cos 15°t$	•	$B_1 \sin 15°t$	•	$A_2 \cos 30°t$	•	$B_2 \sin 30°t$	•	$A_4 \cos 60°t$	•	$B_4 \sin 60°t$
0	+12·46	1	$+1·00A_1$	1	0	1	$+1·00A_2$	1	0	1	$+1·00A_4$	1	0
1	+ 8·76	1	$+0·966A_1$	1	$+0·259B_1$	1	$+0·866A_2$	1	$+0·500B_2$	1	$+0·500A_4$	1	$+0·866B_4$
2	+ 4·00	1	$+0·866A_1$	1	$+0·500B_1$	1	$+0·500A_2$	1	$+0·866B_2$	1	$-0·500A_4$	1	$+0·866B_4$
3	+ 0·04	1	$+0·707A_1$	1	$+0·707B_1$	1	0	1	$+1·00B_2$	1	$-1·00A_4$	1	0
4	− 3·00	1	$+0·500A_1$	1	$+0·866B_1$	1	$-0·500A_2$	1	$+0·866B_2$	1	$-0·500A_4$	1	$-0·866B_4$
5	− 5·97	1	$+0·259A_1$	1	$+0·966B_1$	1	$-0·866A_2$	1	$+0·500B_2$	1	$+0·500A_4$	1	$-0·866B_4$
6	− 9·00	0	0	0	$+1·00B_1$	0	$-1·00A_2$	0	0	0	$+1·00A_4$	0	0
7	−10·76	−1	$-0·259A_1$	−1	$+0·966B_1$	−1	$-0·866A_2$	−1	$-0·500B_2$	−1	$+0·500A_4$	−1	$+0·866B_4$
8	− 9·46	−1	$-0·500A_1$	−1	$+0·866B_1$	−1	$-0·500A_2$	−1	$-0·866B_2$	−1	$-0·500A_4$	−1	$+0·866B_4$
9	− 4·86	−1	$-0·707A_1$	−1	$+0·707B_1$	−1	0	−1	$-1·00B_2$	−1	$-1·00A_4$	−1	0
10	+ 1·00	−1	$-0·866A_1$	−1	$+0·500B_1$	−1	$+0·500A_2$	−1	$-0·866B_2$	−1	$-0·500A_4$	−1	$-0·866B_4$
11	+ 5·07	−1	$-0·966A_1$	−1	$+0·259B_1$	−1	$+0·866A_2$	−1	$-0·500B_2$	−1	$+0·500A_4$	−1	$-0·866B_4$
12	+ 5·54	−1	$-1·00A_1$	−1	0	−1	$+1·00A_2$	−1	0	−1	$+1·00A_4$	−1	0
13	+ 3·10	−1	$-0·966A_1$	−1	$-0·259B_1$	1	$+0·866A_2$	−1	$+0·500B_2$	−1	$+0·500A_4$	−1	$+0·866B_4$
14	+ 0	−1	$-0·866A_1$	−1	$-0·500B_1$	1	$+0·500A_2$	−1	$+0·866B_2$	−1	$-0·500A_4$	−1	$+0·866B_4$
15	− 2·04	−1	$-0·707A_1$	−1	$-0·707B_1$	1	0	−1	$+1·00B_2$	−1	$-1·00A_4$	−1	0
16	− 3·00	−1	$-0·500A_1$	−1	$-0·866B_1$	1	$-0·500A_2$	−1	$+0·866B_2$	−1	$-0·500A_4$	−1	$-0·866B_4$
17	− 3·89	−1	$-0·259A_1$	−1	$-0·966B_1$	1	$-0·866A_2$	−1	$+0·500B_2$	−1	$+0·500A_4$	−1	$-0·866B_4$
18	− 5·00	0	0	0	$-1·00B_1$	0	$-1·00A_2$	0	0	0	$+1·00A_4$	0	0
19	− 5·10	1	$+0·259A_1$	1	$-0·966B_1$	1	$-0·866A_2$	1	$-0·500B_2$	1	$+0·500A_4$	1	$+0·866B_4$
20	− 2·54	1	$+0·500A_1$	1	$-0·866B_1$	1	$-0·500A_2$	1	$-0·866B_2$	1	$-0·500A_4$	1	$+0·866B_4$
21	+ 2·86	1	$+0·707A_1$	1	$-0·707B_1$	1	0	1	$-1·00B_2$	1	$-1·00A_4$	1	0
22	+ 9·00	1	$+0·866A_1$	1	$-0·500B_1$	1	$+0·500A_2$	1	$-0·866B_2$	1	$-0·500A_4$	1	$-0·866B_4$
23	+12·79	1	$+0·966A_1$	1	$-0·259B_1$	1	$+0·866A_2$	1	$-0·500B_2$	1	$+0·500A_4$	1	$-0·866B_4$
	83·92+ 31·32− = 52·60		$15·19A_1$		0		0		0		0		0

TABLE OF MULTIPLIERS FOR $n = 15°, 30°$ AND $60°$

TIME	DIURNAL		SEMI-DIURNAL		QUARTER-DIURNAL	
t	$A_1 \cos 15°t$	$B_1 \sin 15°t$	$A_2 \cos 30°t$	$B_2 \sin 30°t$	$A_4 \cos 60°t$	$B_4 \sin 60°t$
0	1	0	1	0	1	0
1	1	1	1	1	1	1
2	1	1	1	1	−1	1
3	1	1	0	1	−1	0
4	1	1	−1	1	−1	−1
5	1	1	−1	1	1	−1
6	0	1	−1	0	1	0
7	−1	1	−1	−1	1	1
8	−1	1	−1	−1	−1	1
9	−1	1	0	−1	−1	0
10	−1	1	1	−1	−1	−1
11	−1	1	1	−1	1	−1
12	−1	0	1	0	1	0
13	−1	−1	1	1	1	1
14	−1	−1	1	1	−1	1
15	−1	−1	0	1	−1	0
16	−1	−1	−1	1	−1	−1
17	−1	−1	−1	1	1	−1
18	0	−1	−1	0	1	0
19	1	−1	−1	−1	1	1
20	1	−1	−1	−1	−1	1
21	1	−1	0	−1	−1	0
22	1	−1	1	−1	−1	−1
23	1	−1	1	−1	1	−1

Note how the figures in each column have a definite pattern, which is different from that in all the other columns. If, for example, the multipliers in the semi-diurnal sines column are applied to all the equations, then every unknown except B_2 will be eliminated from the sum of the 24 equations.

The complete analysis of the curve in Fig. 2–27(*a*) is shown in the following table, where the multipliers and coefficients (in each case cos *nt* or sin *nt*) of the six unknown quantities are set out. At the foot of each column the factor associated with a particular unknown is given (note the 15·19 for A_1, which has already been used above), as well as the result of adding together the 24 values of H, each of which has been multiplied by the correct multiplier (note again the figure 52·60 for A_1, which has already been used).

HARMONIC ANALYSIS OF THE CURVE IN FIG. 2–26(*a*)

TIME t	OBSERVED HEIGHT H	DIURNAL				SEMI-DIURNAL				QUARTER-DIURNAL			
		×	A_1	×	B_1	×	A_2	×	B_2	×	A_4	×	B_4
0	+12·46	1	+1·00	0	0	1	+1·00	0	0	1	+1·00	0	0
1	+ 8·76	1	+0·966	1	+0·259	1	+0·866	1	+0·500	1	+0·500	1	+0·866
2	+ 4·00	1	+0·866	1	+0·500	1	+0·500	1	+0·866	−1	−0·500	1	+0·866
3	+ 0·04	1	+0·707	1	+0·707	0	0	1	+1·00	−1	−1·00	0	0
4	− 3·00	1	+0·500	1	+0·866	−1	−0·500	1	+0·866	−1	−0·500	−1	−0·866
5	− 5·97	1	+0·259	1	+0·966	−1	−0·866	1	+0·500	1	+0·500	−1	−0·866
6	− 9·00	0	0	1	+1·00	−1	−1·00	0	0	1	+1·00	0	0
7	−10·76	−1	−0·259	1	+0·966	−1	−0·866	−1	−0·500	1	+0·500	1	+0·866
8	− 9·46	−1	−0·500	1	+0·866	−1	−0·500	−1	−0·866	−1	−0·500	1	+0·866
9	− 4·86	−1	−0·707	1	+0·707	0	0	−1	−1·00	−1	−1·00	0	0
10	+ 1·00	−1	−0·866	1	+0·500	1	+0·500	−1	−0·866	−1	−0·500	−1	−0·866
11	+ 5·07	−1	−0·966	1	+0·259	1	+0·866	−1	−0·500	1	+0·500	−1	−0·866
12	+ 5·54	−1	−1·00	0	0	1	+1·00	0	0	1	+1·00	0	0
13	+ 3·10	−1	−0·966	−1	−0·259	1	+0·866	1	+0·500	1	+0·500	1	+0·866
14	0	−1	−0·866	−1	−0·500	1	+0·500	1	+0·866	−1	−0·500	1	+0·866
15	− 2·04	−1	−0·707	−1	−0·707	0	0	1	+1·00	−1	−1·00	0	0
16	− 3·00	−1	−0·500	−1	−0·866	−1	−0·500	1	+0·866	−1	−0·500	−1	−0·866
17	− 3·89	−1	−0·259	−1	−0·966	−1	−0·866	1	+0·500	1	+0·500	−1	−0·866
18	− 5·00	0	0	−1	−1·00	−1	−1·00	0	0	1	+1·00	0	0
19	− 5·10	1	+0·259	−1	−0·966	−1	−0·866	−1	−0·500	1	+0·500	1	+0·866
20	− 2·54	1	+0·500	−1	−0·866	−1	−0·500	−1	−0·866	−1	−0·500	1	+0·866
21	+ 2·86	1	+0·707	−1	−0·707	0	0	−1	−1·00	−1	−1·00	0	0
22	+ 9·00	1	+0·866	−1	−0·500	1	+0·500	−1	−0·866	−1	−0·500	−1	−0·866
23	+12·79	1	+0·966	−1	−0·259	1	+0·866	−1	−0·500	1	+0·500	−1	−0·866
	Factors		15·19		15·19		14·93		14·93		16·00		13·86
Sums of Hs			+52·60		−30·36		119·64		0		16·00		−24·00

From the figures at the foot of the table:

For the Diurnal Constituent (the Fundamental in this Case)

$$15{\cdot}19A_1 = +52{\cdot}60 \text{ and } A_1 = 3{\cdot}46$$
$$-15{\cdot}19B_1 = -30{\cdot}36^{*} \text{ and } B_1 = 2{\cdot}00.$$

---

* This figure should have been 30·38. The slight error is due to rounding off the decimals of H to two places.

Therefore $\tan \varphi = B/A = \frac{2{\cdot}00}{3{\cdot}46} = 0{\cdot}577$

and $\varphi = 30°$.

$R^2 = A^2 + B^2 = 16$

and $R = 4$.

These results may be compared with Fig. 2–27(*b*).

For the Semi-Diurnal Constituent

$$14{\cdot}93A_2 = 119{\cdot}64, \text{ and } A_2 = 8{\cdot}00$$

$$-14{\cdot}93B_2 = 0, \text{ and } B_2 = 0.$$

Therefore $\tan \varphi = 0$

and $\varphi = 0°$.

$R^2 = A^2 + B^2 = 64$

and $R = 8$.

Compare these results with Fig. 2–27(*c*).

For the Quarter-Diurnal Constituent

$$16{\cdot}00A_4 = 16{\cdot}00, \text{ and } A_4 = 1{\cdot}00$$

$$-13{\cdot}86B_4 = -24{\cdot}00, \text{ and } B_4 = 1{\cdot}73.$$

Therefore $\tan \varphi = 1{\cdot}73$

and $\varphi = 60°$.

$R^2 = A^2 + B^2 = 4$

and $R = 2$.

These results may be compared with Fig. 2–27(*d*).

b. Harmonic analysis applied to tides; compound harmonics and modulation

The simple process of harmonic analysis described in **a** above may be used to split up any complex wave form which repeats itself into a series of pure cosine curves, each of which has an unvarying amplitude. It cannot be used as it stands for the analysis of tides, since the tidal movements do not (so far as is known) ever repeat themselves exactly; however, in a modified form it will give very reasonable results when applied to actual observations. The reader will see many points of similarity between it and the processes set out in *The Admiralty Semi-Graphic Method of Harmonic Tidal Analysis* (*Admiralty Tidal Handbook No. 1*).

From its very earliest days tidal theory has been very closely connected with astronomical theory. This is only natural, since the astronomical forces which hold the sun, earth and moon in stable orbits are the primary cause of the tides. These astronomical forces have been analysed rigorously and a great deal is known about them.*

From this astronomical theory the tidal specialist can obtain a theoretical expression which gives the total tide raising force at any point on the earth's surface at a particular time. It so happens that this total tide raising force is conveniently expressed as the sum of a number of cosine curves, whose amplitude and frequency may vary slowly with time.

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* Brown's theory of the motion of the moon is perhaps the most important individual work in this analysis.

Consider the tide raising force caused by the fictitious mean moon, which proceeds round the celestial equator at a fixed distance and fixed speed. Astronomical theory provides it as the sum of two pure cosine curves; one with a period of about 24 hours 50 minutes and very small amplitude which will be neglected for the moment, and one with quite a large amplitude and period of 12 hours 25 minutes approximately. This last function is known as M_2, or the semi-diurnal tide raising force constituent of the mean moon. It has a fixed amplitude and fixed frequency and may be expressed by the simple harmonic

$$\text{h of } M_2 = R\cos(\varphi + nt)$$

where h = height
R = amplitude
φ = phase at time ($t = 0$)
n = frequency (speed) = 28°·934/hour in this case
and t = time.

Having started with a fictitious mean moon moving round the celestial equator in a circular orbit at a fixed speed, the astronomer puts it into an elliptical orbit, still in the plane of the equator, and calculates how his original simple harmonic expression must be modified to allow for this change. The tidal specialist follows suit. If the moon moves in an elliptical orbit, it will change its distance and orbital velocity, moving fastest in its orbit when it is at perigee. Clearly the amplitude and frequency of the expression for M_2 above must now be made to vary with time; the original pure cosine curve for M_2 must in fact be amplitude and frequency modulated.

In the same way the semi-diurnal tide raising force constituent of the mean sun must be amplitude and frequency modulated.

The total semi-diurnal tide raising force at any place will then be the sum of these two expressions (one for the moon and one for the sun). Each expression will have a frequency which bears no simple relationship to that of the other or to a fundamental, and each frequency will be modulated in a very complex way. Each is a compound harmonic.

The simple process of harmonic analysis described in **a** above will not, even when modified, handle expressions whose amplitude R and frequency n vary. Fortunately it is possible to express these compound and very complex harmonics as the sum of several simple harmonics, whose amplitude and frequency do not vary.

(i) Compound harmonics; amplitude and frequency modulation. A pure cosine wave form may be expressed by the formula

$$h = R\cos(\varphi + nt)$$

where h = height (+ above and − below the x axis)
R = amplitude
φ = phase at time ($t = 0$)
n = rate of change of phase
and t = time.

Note that R, φ and n are all constants; the expression is a simple harmonic.

Now if R is made to vary with time, the wave form is said to be amplitude modulated.

If n is made to vary with time, the wave form is frequency modulated, and if φ is made to vary the wave form is phase modulated. The analogies with radio theory are exact. In all three cases the expression becomes a compound harmonic. Amplitude and frequency modulation are used a great deal in tidal analysis, generally together; phase modulation, which may be considered to be another form of frequency modulation, is used very little.

Consider the expression for the semi-diurnal tide raising force constituent of the mean moon (M_2) referred to above. If the phase at time ($t = 0$) is 360°, it is

$$h = R \cos nt.$$

To allow for the fact that the real moon moves in an elliptical orbit this expression must be both amplitude and frequency modulated, i.e. R and n must be made to vary with time.

Suppose for the moment that only the amplitude varies. Then the formula might become

$$h = (R + R_1 \cos mt) \cos nt$$

where R_1 is the amplitude of the modulating wave and m its frequency or speed.

This awkward compound harmonic may be modified in the following way, so that the term inside the bracket is replaced by something that can be handled more easily:

$$\begin{aligned} h &= (R + R_1 \cos mt) \cos nt \\ &= R \cos nt + R_1 \cos nt \,.\, \cos mt. \end{aligned}$$

Now,

$$\begin{aligned} \cos nt \,.\, \cos mt &= \cos (nt + mt) + \sin nt \,.\, \sin mt^* \\ &= \cos (nt + mt) + \cos (nt - mt) - \cos nt \,.\, \cos mt^* \end{aligned}$$

therefore, $$2 \cos nt \,.\, \cos mt = \cos (nt + mt) + \cos (nt - mt)$$

and $$\cos nt \,.\, \cos mt = \tfrac{1}{2} \cos (nt + mt) + \tfrac{1}{2} \cos (nt - mt).$$

Substituting in the formula for h,

$$\begin{aligned} h &= R \cos nt + \tfrac{1}{2} R_1 \cos (nt + mt) + \tfrac{1}{2} R_1 \cos (nt - mt) \\ &= R \cos nt + \tfrac{1}{2} R_1 \cos (n + m) t + \tfrac{1}{2} R_1 \cos (n - m) t. \end{aligned}$$

This formula is most important. It shows that when a wave of amplitude R and frequency n ($h = R \cos nt$) is amplitude modulated by a wave of amplitude R_1 and frequency m, the resulting curve will be expressed by adding two pure cosine curves, each of amplitude $\frac{1}{2} R_1$ and having frequencies $n + m$ and $n - m$ respectively, to the original wave. Once more the analogy with radio theory is exact; the frequencies $n + m$ and $n - m$ are the sidebands, whilst n is the carrier.

Thus the changing distance of the real moon may be allowed for by adding two new constituents to M_2. If the speed of M_2 is n and the speed of the modulating force is m (both these are obtained from astronomical theory) then the speeds of the new constituents are $n + m$ and $n - m$; it is important to note that the amplitudes of the two new constituents are equal.

How is the frequency modulation of M_2 carried out, to allow for the fact that the real moon changes its orbital speed? The problem can be explained most easily by graphical methods.

In Fig. 2–28(*a*) a vector of length R is rotating anticlockwise at a frequency (speed) n. At any moment the height h is equal to $R \cos nt$. The diagram may be used to solve the simple harmonic equation referred to above.

Now suppose that this vector is amplitude modulated, so that R changes its length with time. As has been seen above, two additional vectors are introduced; if the modulating frequency is m their speeds will be $n+m$ and $n-m$, and they will have equal amplitudes. Consider their motion relative to an observer standing on, and moving round with the original vector R. It is illustrated in Fig. 2–28(*b*). R is now stopped, and the two new vectors are rotating in opposite directions with equal speeds of $+m$ and $-m$. Their resultant will always be in line with R, which will therefore vary in length between $R + R_1$ and $R - R_1$.

---

* Both these steps depend on the basic formulae for the cosine of the sum and difference of two angles; thus

$$\cos (nt + mt) = \cos nt \,.\, \cos mt - \sin nt \,.\, \sin mt$$

and

$$\cos (nt - mt) = \cos nt \,.\, \cos mt + \sin nt \,.\, \sin mt.$$

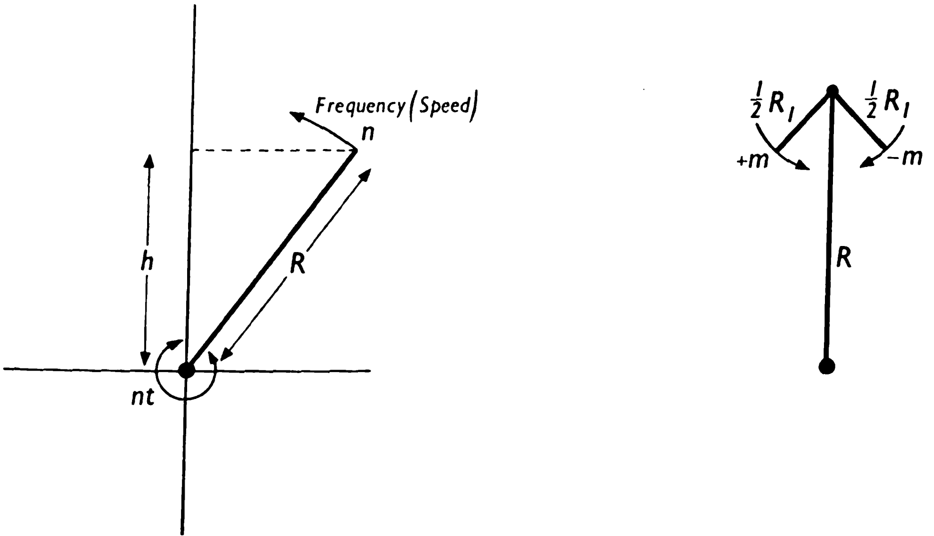
In order to introduce frequency modulation, it is only necessary to vary the speed of rotation of the vector R in Fig. 2–28(*a*), or in other words to make R in Fig. 2–28(*b*) swing backwards and forwards. Suppose that the two amplitude modulating vectors in Fig. 2–28(*b*) do not have equal amplitudes; then their resultant will ***not*** always be in line with R and the latter *will* swing back and forth. In the extreme case one of the modulating vectors may be removed altogether, to produce the maximum possible swing in R in these circumstances. Frequency modulation is now taking place, in addition to the more easily recognised amplitude modulation.

In the case of the moon the constituent M$_2$ must be amplitude and frequency modulated. As will be seen, this is achieved by adding to it two new simple harmonic constituents of speeds $n + m$ and $n - m$ (which are obtained from astronomical theory) and very different amplitudes.

This theme constantly recurs in tidal analysis and it is most important. It may be summarised as follows:

(1) A basic constituent has constant frequency n and constant amplitude R.

(2) It must be modulated to allow for the observed facts. The modulating frequency m of amplitude R$_1$ can be calculated from astronomical theory.



(*a*) (*b*)

Fig. 2–28

(3) Two new frequencies, $n + m$ and $n - m$, must be added to (1). If their amplitudes are equal, the original frequency will be amplitude modulated only. If their amplitudes are not equal, frequency modulation will also be present. The degree of either can be adjusted by altering the amplitudes of $n + m$ and $n - m$, either together or independently.

(4) There is no limit to the number of pairs of sideband frequencies which may be added to the original basic constituent.

11. Tide Raising Force Constituents

The total tide raising force is equal to the sum of several basic 'carrier' wave forms, each of which is modulated in various ways. These basic wave forms are:

(1) A pair of semi-diurnal constituents, M_2 for the moon and S_2 for the sun, which both have periods of about half a day and speeds near 30°/hour.

(2) A pair of diurnal constituents for the moon, K_1 and O_1, which have periods of about one day and speeds near 15°/hour.

(3) A pair of diurnal constituents for the sun, K_1 and P_1, which also have periods of about one day and speeds near 15°/hour. As will be seen the sun's K_1 has exactly the same speed as the moon's K_1, and is therefore indistinguishable from it in practice.

(4) A pair of constituents for the moon, M*f* and M*m*, which have speeds of about 1°/hour and $\frac{1}{2}$°/hour respectively, and periods of about a fortnight and a month.

(5) A pair of constituents for the sun, S*sa* and S*a*, which have speeds of about $\frac{1}{12}$°/hour and $\frac{1}{24}$°/hour respectively, and periods of about six months and one year.

These last two pairs, (4) and (5), have amplitudes fairly small compared to those of the first three pairs; in practice it is often very difficult to isolate them from a series of tidal observations.

a. Semi-diurnal constituents M_2 and S_2; springs and neaps; nodal corrections

The basic carrier wave produced by the semi-diurnal part of the attractive force of a fictitious moon, which proceeds round the celestial equator at a fixed distance in a period of 24·84 hours, is called M_2.* It has a period of 12·42 hours, a speed (frequency) of 360°/12·42 = 28°·984/hour and an amplitude which is arbitrarily assumed to be 1.

The basic carrier wave produced by the semi-diurnal part of the attractive force of the mean sun, which proceeds round the celestial equator at a fixed distance in a period of 24 hours exactly, is called S_2. S_2 has a period of 12 hours, a speed of 30°·00/hour and an amplitude 0·46 that of M_2 (see Section **3a** of this chapter).

These two constituents combine to produce the basic semi-diurnal tide raising force. When they are in phase, their amplitudes will be added, producing spring tides. When they have exactly opposite phases (180° apart) their amplitudes will be subtracted, producing neap tides.

The difference of speed between S_2 and M_2 is 30°·00–28°·984 = 1°·016/hour; a wave form with this speed would have a period of 14·765 days, which is that of half one lunation of 29·531 days. Thus theory agrees with common sense in saying that spring and neap tides depend on the phases of the moon and occur once a fortnight.

The reaction between M_2 and S_2 could be represented vectorially in the manner described in Section **10b(i)** above and Fig. 2–28. A 'carrier vector' M_2 is modulated by one sideband only, S_2. The amplitude of their resultant will vary once a fortnight as described above. But since there is only one sideband, frequency modulation will also be present. Therefore, the time differences between the various high and low waters of the combined ($M_2 + S_2$) tide will vary, and the variation itself will have a period of a fortnight. This variation of the intervals between successive high and low waters has in the past been known as the priming and lagging of the tides; these terms are not used in modern practice.

If M_2 and S_2 were the only tidal force constituents then springs and neaps would repeat themselves in exactly the same way every lunation. However, each of them is itself modulated by many other frequencies, in the way described below.

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* In tidal work the suffix always indicates the number of cycles per day. Thus M_2 is semi-diurnal, K_1 is diurnal and MS_4 is quarter-diurnal.

(i) Semi-diurnal modulations of M_2; constituents N_2, L_2, ν_2, λ_2, μ_2, S_2, K_2. The distance of the actual moon varies, with a period of 27·5546 days, or 661·31 hours (this is the period from perigee to perigee). Its orbital speed will also vary with the same period, being fastest when it is closest. M_2 must therefore be amplitude and frequency modulated at a speed (frequency) of $360°/661{\cdot}31 = 0°{\cdot}544$/hour. This modulation may be represented by applying the process described in Section **10b(i)** above; two new constituents are produced, in addition to M_2. They will have unequal amplitudes, in order that amplitude and frequency modulation may take place. They are:

N_2, with a speed of $28°{\cdot}984 - 0°{\cdot}544 = 28°{\cdot}440$/hour, and an amplitude 0·20 that of M_2, and

L_2, with a speed of $28°{\cdot}984 + 0°{\cdot}544 = 29°{\cdot}528$/hour, and an amplitude 0·03 that of M_2. L_2 is sometimes neglected in practice.

When N_2 and L_2 have been added to M_2 the moon is moving in an elliptical orbit in the plane of the celestial equator. Allowance must now be made for the fact that the sun attracts the moon more when it is new (and therefore closer to the sun) than when it is full, making the ellipse slightly pear shaped, and also affects its orbital speed; when the moon is proceeding towards the sun (around last quarter) its orbital velocity will clearly be greater than when it is proceeding away from the sun (around first quarter).

Several modulating frequencies are involved. The most important have periods of 31·8133 and 14·7653 days, and speeds of 0°·471/hour and 1°·016/hour.*

From these, four new constituents are produced, as follows:

ν_2, with a speed of $28°{\cdot}984 - 0°{\cdot}471 = 28°{\cdot}513$/hour, and an amplitude 0·04 that of M_2;

λ_2, with a speed of $28°{\cdot}984 + 0°{\cdot}471 = 29°{\cdot}455$/hour, and an amplitude 0·01 that of M_2;

μ_2, with a speed of $28°{\cdot}984 - 1°{\cdot}016 = 27°{\cdot}968$/hour, and an amplitude 0·02 that of M_2;

S_2, with a speed of $28°{\cdot}984 + 1°{\cdot}016 = 30°{\cdot}000$/hour and a minute amplitude.

This last constituent is not the S_2 caused by the sun, but a very small 'perturbation' of it caused by the moon. As it cannot be distinguished from the main S_2, having the same frequency, it is given the same name.

Note that the frequency modulation takes place 'automatically', since the individual constituents in the two pairs of sidebands have different amplitudes.

Now let the moon start moving in an orbital plane inclined at about 5° to the ecliptic. Its changing declination must be taken into account. Since the effect is the same whether the moon is north or south of the equator, the period of the new modulating frequency will be half that of a complete declination cycle of 27·3216 days, or 13·6608 days. This corresponds to a speed of 1°·098/hour, and therefore the two new constituents will be:

An unnamed one with a speed of $28°{\cdot}984 - 1°{\cdot}098 = 27°{\cdot}886$/hour, and negligible amplitude, and K_2 with a speed of $28°{\cdot}984 + 1°{\cdot}098 = 30°{\cdot}082$/hour, and an amplitude 0·09 that of M_2.

Note that once again the amplitudes of these two new sideband constituents are different, so that M_2 will be both amplitude and frequency modulated. As will be seen below a constituent with the same speed as that of K_2 above is produced in the process of modulating S_2. Since they cannot be separated in practice their combined amplitude (0·13 that of M_2) is generally quoted.

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* Note that this one is clearly going to affect springs and neaps, since its speed is equal to that of S_2–M_2.

(ii) Nodal corrections. From the above it can be seen that if all these sideband constituents are added to M_2, reasonable* allowance is made for the motions of the actual moon, provided its orbit remains fixed in space. Unfortunately it does not. It has been seen in Section 1b of this chapter that its orbit is inclined at about 5° to the ecliptic and that the nodes move right round the ecliptic in a period of 18·61 years; in addition the position of the moon's perigee makes one revolution in about nine years, in the opposite direction to the movement of the nodes. To allow for all this the constituents connected with the moon should themselves be modulated by frequencies having periods of about 9 and 19 years. Since these periods are so long, and the amplitudes of the new wave forms are small, mean values of the main lunar constituents are tabulated. The long period, or nodal corrections, are worked out for each complete cycle of about 19 years, and then applied to the mean values of the constituents.† The mean amplitude of each constituent must be multiplied by a factor f and its phase increased by a quantity u°, to obtain its value at a particular time; both these quantities are tabulated for the main constituents which have anything to do with the moon in *Table VIII* of the *Admiralty Tide Tables Vols. II and III.*

Note that in theory similar corrections should be made to all the sun's constituents, to allow for precession and the movement of the earth's perihelion position. Since both these motions have periods of several thousand years the practical analyst is not concerned with them.

(iii) Semi-diurnal modulations of S_2; constituents T_2, R_2, K_2. The sun's distance from the earth changes, with a period of 365·24 days, or 8765·8 hours; its 'orbital speed' also varies with the same period, being fastest when it is closest. There fore S_2 must be modulated by a frequency having a speed of $360°/8765{\cdot}8 = 0°{\cdot}041$/hour. Two new constituents are produced:

T_2 with a speed of $30° - 0°{\cdot}041 = 29°{\cdot}959$/hour, and an amplitude 0·03 that of M_2, and

R_2, with a speed of $30° + 0°{\cdot}041 = 30°{\cdot}041$/hour, and an amplitude 0·004 that of M_2. R_2 is generally neglected in practice.

T_2 and R_2 for the sun are analagous to N_2 and L_2 for the moon. Note that since their amplitudes are different S_2 will be both amplitude and frequency modulated, which is what is required.

The sun goes through a complete cycle of declination in a year, and since the effect on S_2 is the same whether it is north or south of the equator, the modulating frequency necessary will have a speed twice that of the one mentioned above, or 0°·082/hour. Once more two new constituents are produced:

K_2, with a speed of $30° + 0°{\cdot}082 = 30°{\cdot}082$/hour, and an amplitude 0·04 that of M_2, and an unnamed constituent, with a speed of $30° - 0°{\cdot}082 = 29°{\cdot}918$/hour, and an amplitude 0·001 that of M_2, which is generally neglected.

Amplitude and frequency modulation of S_2 both take place. Note that K_2 here has exactly the same speed as the moon's K_2 referred to in **(i)** above. They cannot be separated, and are therefore treated as one constituent with an amplitude $0{\cdot}09 + 0{\cdot}04 = 0{\cdot}13$ that of M_2.

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* The reader should not imagine that the word reasonable here means exact. Only the most important constituents are referred to; those omitted are all very small and will not affect the practical observation and prediction of tides appreciably.

† This is the only place where the tidal analyst allows the amplitudes of his constituents to vary. He does so because the variation is very slow indeed and is not appreciable over a period of one month. Although the inclination of the moon's orbit to the ecliptic is assumed here to be fixed, it does in fact vary very slightly (by 18 minutes of arc) in a period of about six months. Again the movement of the moon's nodes round the ecliptic is not quite regular.

b. Lunar diurnal constituents K_1 and O_1

The constituents M_2 and S_2 beat together to form spring and neap tides every half lunation (see **a** above). The moon's diurnal tide raising force, which has a period of about 24·84 hours, has an amplitude which varies with the moon's declination. When the moon is on the celestial equator, this amplitude will be very small (but not quite zero)* and just over 6½ days later, when the moon's declination is a maximum, it will have its greatest value. The period of this fluctuation in amplitude of the moon's diurnal tide raising force (which is analogous to the spring-neap period), is that of half a cycle of lunar declination, or 13·6608 days; its corresponding frequency or speed would be 1°·098/hour.

The lunar constituents K_1 and O_1 combine to express the diurnal tide raising force of a fictitious moon which moves in a circular orbit, but changes its declination between the mean limits of declination reached by the real moon.

The lunar K_1 has a speed of 15°·041/hour and an amplitude 0·40 that of M_2. As will be seen it cannot be distinguished from the solar K_1 which has the same speed. In practice these two are treated as a luni-solar K_1 having an amplitude equal to the sum of theirs.

O_1 has a speed of 13°·943/hour and an amplitude 0·41 that of M_2. The difference between the amplitudes of the lunar K_1 and O_1 is actually 0·015.

Now imagine these two constituents beating together in a way similar to M_2 and S_2. When they are in phase their amplitudes will add and the moon's diurnal tide (diurnal inequality) will be greatest; the moon will be at its maximum declination north or south. When they have exactly opposite phases (180° apart) their amplitudes will be subtracted; the diurnal tide will be very small indeed, but will not quite disappear, and the moon will be on the celestial equator. The difference in speed between K_1 and O_1 is $15^\circ{\cdot}041 - 13^\circ{\cdot}943 = 1^\circ{\cdot}098$/hour. A waveform with this speed would have a period of 13·6608 days, which is half that of a cycle of lunar declination.

In the same way as M_2 and S_2 produce a 'priming' and 'lagging' of the semi-diurnal tide (see **a** above), so K_1 and O_1 will cause the moon's diurnal tide to prime and lag, and intervals between high waters and low waters will vary.

K_1 and O_1 must, of course, be modified by nodal corrections in the way described in **a(ii)** above, to allow for the changes in the moon's orbit which take place with periods of about 9 and 19 years. They are also modulated in the way described below.

(i) Modulations of lunar K_1 and O_1; constituents J_1, M_1, Q_1. The lunar K_1 and O_1 above represent a moon which changes its declination but whose orbit is circular. Allowance must be made for the fact that this orbit is really an ellipse, and both must therefore be modulated by a waveform with a period of 661·31 hours (this is the period from perigee to perigee), and a speed of 0°·544/hour.† Two new pairs of constituents are produced.

For K_1 they are:

J_1 with a speed of $15^\circ{\cdot}041 + 0^\circ{\cdot}544 = 15^\circ{\cdot}585$/hour, and an amplitude 0·03 that of M_2, and

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* The tide raising force on the side of the earth facing the moon is very slightly greater than that on the side of the earth away from the moon. Hence, even when the moon is over the equator there will be a very small diurnal inequality.

† Note that this is the same speed that produced N_2 and L_2 from M_2 in **a**(i) above.

M_1 with a speed of 15°·041 − 0°·544 = 14°·497/hour, and an amplitude also 0·03 that of M_2.

For O_1 they are:

Another M_1 with a speed of 13°·943 + 0°·544 = 14°·487/hour, and an amplitude 0·01 that of M_2, and Q_1 with a speed of 13°·943 − 0°·544 = 13°·399/hour, and an amplitude 0·08 that of M_2.

Note that K_1 will be amplitude modulated only, since J_1 and the first M_1 have equal amplitudes; but that O_1 will be amplitude and frequency modulated, since the sidebands have unequal amplitudes.

In practice it is very difficult to separate the two M_1s above (it will take over four days for their relative phases to change 1°); they are therefore generally treated as one constituent with a speed of 14°·492/hour and a variable amplitude about 0·02 that of M_2.

In theory additional modulating frequencies should be introduced to allow for the fact that the sun causes the moon's orbit to become very slightly pear shaped (see ν_2, λ_2, etc., in **a**(i) above), but their amplitudes are so small that they are generally neglected in practical work.

c. Solar diurnal constituents K_1 and P_1

The sun's diurnal tide raising force has a period of about 24 hours, and an amplitude which varies with the sun's declination. When the sun is on the celestial equator this amplitude will be very small (but not quite zero)* and about three months later, when the sun's declination is a maximum, it will have its greatest value.

The period of this fluctuation in amplitude of the sun's diurnal tide raising force (which is analogous to the spring-neap period), is that of half a cycle of solar declination or 182·62 days; its corresponding frequency or speed would be 0°·082/hour.

The solar constituents K_1 and P_1 combine to express the diurnal tide raising force of a fictitious sun which moves in a circular orbit, but changes its declination between the limits of declination reached by the true sun, i.e. this fictitious sun moves in a circular orbit in the plane of the ecliptic.

The solar K_1 has a speed of 15°·041/hour and an amplitude 0·18 that of M_2. It has exactly the same speed as the lunar K_1, and cannot in practice be distinguished from it. The two are combined to form a luni-solar K_1, having an amplitude of 0·40 + 0·18 = 0·58 that of M_2.

P_1 has a speed of 14°·959/hour, and an amplitude 0·19 that of M_2. The difference between the amplitudes of the solar K_1 and P_1 is actually 0·007.

These two constituents beat together in a way similar to the lunar K_1 and O_1 and M_2 and S_2 (see **b** above). When the sun has a maximum declination north or south they will be in phase; their amplitudes will add and the sun's diurnal tide will be greatest. When the sun is on the celestial equator they will have exactly opposite phases (180° apart); their amplitudes will be subtracted and the sun's diurnal tide will be very small indeed, but will not quite disappear. The difference in speed between K_1 and P_1 is 15°·041 − 14°·959 = 0°·082/hour. A waveform with this speed would have a period of 182·62 days, which has been seen above to be that of half a cycle of solar declination.

The sun's K_1 and P_1 produce a slight 'priming' and 'lagging' of the sun's diurnal tide, and therefore the intervals between its high waters and low waters will vary slightly. This effect is similar to that produced by M_2 and S_2 for the semi-diurnal tide, and K_1 and O_1 for the lunar diurnal tide.

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* The reason is the same as that which applies to the moon's diurnal tide raising force. See the footnote in **b** above.

In theory both K_1 and P_1 should themselves be modulated to allow for the fact that the earth's orbit round the sun is elliptical, and not circular. In practice, the amplitudes of the new constituents are so small that they are generally neglected.

d. Lunar 'long period' constituents M_f and M_m

The arguments set out in sections **a(i)** and **b** above assume that the moon changes its declination and distance from the earth sinusoidally, i.e. that its changes in declination and distance plotted against time would take the form of pure sine or cosine curves. It does not quite do this. To allow for this fact the so-called long period constituents are added to M_2.

M_f has a period of 13·6608 days, a speed of 1°·098/hour and an amplitude 0·16 that of M_2. It deals with the declination effects, as its period is that of half a cycle of the moon's declination.

M_m has a period of 27·5546 days (the period from perigee to perigee), a speed of 0°·544/hour, and an amplitude 0·08 that of M_2. It deals with the irregularities in the moon's rate of change of distance and speed in orbit.

Since both these constituents have long periods and small amplitudes, they cannot in practice be distinguished from changes brought about by meteorological effects, unless observations are obtained over a period of several months. The hydrographic surveyor will therefore generally find that he must neglect them. In some places M_f and M_m are affected by shallow water constituents with identical speeds.

e. Solar 'long period' constituents S_{sa} and S_a

In theory, two long period constituents must be added to S_2 to allow for the fact that the changes in the sun's declination and distance do not take place quite smoothly and evenly. S_{sa} has a period of about six months and S_a one of about one year.

In practice it is found that their periods are so long and their amplitudes so small that they cannot be distinguished at all from meteorological effects. Thus, an analyst attempting to find them from tidal observations made on the north-west coast of Burma would almost certainly isolate instead the changes in mean sea level caused by the north-east and south-west monsoons.

f. Summary of the total tide raising force

Summarising Sections **a** to **e** above, the total tide raising force may be represented by the following equation:

$$\begin{aligned}\text{Total force} &= \text{moon's semi-diurnal group} + \text{sun's semi-}\\ &\quad\text{diurnal group} + \text{moon's diurnal group} +\\ &\quad\text{sun's diurnal group} + \text{long period group} +\\ &\quad\text{moon's nodal corrections}\\ &= (M_2 + N_2 + L_2 + \nu_2 + \lambda_2 + \mu_2 + S_2 + K_2)\\ &\quad + (S_2 + T_2 + R_2 + K_2)\\ &\quad + (K_1 + O_1 + J_1 + M_1 + Q_1) + (K_1 + P_1)\\ &\quad + (M_f + M_m + S_a + S_{sa}) + \text{nodal corrections.}\end{aligned}$$

Each symbol in this formula represents a pure cosine curve. In Fig. 2-27 three pure cosine curves were added together to produce the curve shown there. In this case 23 pure cosine curves must be added together to produce the curve representing the total tidal force.* The difference between these two cases is not one of method, but only of the labour involved in making the addition. The nodal corrections could be applied by adding several more terms to the series; in fact it is easier and more convenient to apply them in the way described in **a(ii)** above.

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* This may seem a great many terms representing the tidal force. In fact it is only a small fraction of those which are necessary to represent it precisely. Fortunately this number is more than enough for the practical surveyor.

g. Higher harmonics and shallow water constituents

All the tide raising force constituents mentioned in **f** above are pure cosine curves. Imagine that they take the form of a number of frequency and amplitude modulated wireless carrier waves arriving at the aerial of a specially designed radio receiver. This receiver, unlike most ordinary ones, is intended to receive them all equally well, i.e. its tuning is very unselective. If the receiver has been made properly all these signals will pass through it without distortion, and the output from the loudspeaker will faithfully represent the input at the aerial. But if the receiver has been badly designed or made it will distort them, perhaps responding far too much to one particular frequency and not enough to others, and even generating higher harmonics within itself. Although these distortions do not arise until the various modulated carrier waves start to pass through the receiver, they may, by the process of harmonic analysis, be represented as simple harmonics of the incoming carrier frequencies, i.e. their wavelengths will be simple fractions of the various incoming wavelengths. Thus they will depend partly on the nature of the input signals and partly on the nature of the receiver, and they will almost certainly be different for each receiver.

The analogy with the tides is very close. The tide raising force constituents act on a body of water, which may be likened to the radio receiver. This water, particularly if it is very shallow, will almost certainly distort them, producing shallow water constituents. It is important to realise that these constituents are not produced by the astronomical forces which hold the various members of the solar system in their orbits, but by the inertia, friction and resonance of a particular body of water on the earth. The tidal analyst finds it convenient to describe and handle them in terms of the higher harmonics of the astronomically generated tide raising forces.

These shallow water constituents vary from place to place and can only be found by analysing a series of tidal observations. Experience indicates that the even harmonics, semi-diurnal, quarter-diurnal, sixth-diurnal and so on, are more important than the odd ones. The hydrographic surveyor is not very likely to be concerned with harmonics higher than quarter-diurnal, although the tidal specialist anxious to produce accurate predictions for, say, the port of Southampton would need to take many more into account.

h. Phase and amplitude of the tide raising force; constituents; (E + u) and fF

If the nodal corrections referred to in section 11**a**(ii) above are neglected the phase E of any tide raising force constituent may be calculated for any time on the Greenwich meridian. This phase will be the same in all latitudes and it will increase at a constant rate, known as the speed of the constituent. The nodal corrections are applied as phase shifts, which vary slowly with time, so that the true theoretical phase of a constituent is (E + u), where u is the nodal phase shift. The values of (E + u) at Greenwich for the most important constituents are published annually in *Table VIII* of the *Admiralty Tide Tables Vols. II and III*; the tabulated quantities are for 0 hours G.M.T. A value at any other time *t* hours G.M.T. may be obtained by adding to the tabulated value an angle equal to *t* times the speed of the constituent.

If nodal corrections are neglected the mean amplitude of any tide raising force constituent in a particular latitude would be F; it would change with the observer's latitude, but could easily be obtained from astronomical theory. The nodal corrections are applied as a factor f, so that the corrected amplitude becomes fF. This factor f, which varies very slowly about a mean value of 1, is tabulated for each month of the year, for the more important constituents, in *Table VIII* of the *Admiralty Tide Tables, Vols. II and III.*

As will be seen in Section **12b** below the actual values of F are not needed in tidal analysis, nor for the prediction of tides; for this reason they are not published in the *Tide Tables*. They have, however, been calculated, and can be found in books which deal particularly with the astronomical theory of tides.

12. Practical Tide Analysis; Tidal Constituents and Constants g and H

a. The phase lag g

The speed of any constituent of the actual tide at any place is the same as that of the tide raising force constituent which produces it. Its phase is defined as lagging behind that of the tide raising force constituent by a fixed amount g, which is known as the phase lag constant of the place.

Thus if the phase of a particular tide raising force constituent at Greenwich at hour t G.M.T. is $(E + u)$, then the phase of the corresponding tidal constituent at any place at hour t local time will be $(E + u) - g$. Note that g automatically takes care of the observer's longitude and local time, as well as the actual phase lag, since it converts the phase of the tide raising force constituent at Greenwich in G.M.T. directly into that of the tidal constituent at any place in local time. For this reason it is vital that the local time being kept should always be recorded whenever values of g are quoted. This quantity g forms one of the constants for a particular tidal constituent and a particular place.

When a tidal analysis is made one of the end products is the phase of each tidal constituent at a particular time, which is usually the mid point of the period of observation. Suppose that the phase of a certain constituent found in this way is φ; then, applying the formula set out above,

$$(E + u) - g = \varphi$$

and $g = (E + u) - \varphi$

= (Theoretical phase of the tide raising force constituent at Greenwich at hour t G.M.T.)−(Observed phase of the actual tidal constituent at the place concerned at the same hour local time).

b. The amplitude H

The amplitude F of any tide raising force constituent at any place may be calculated from astronomical theory. If the waters of the earth had no inertia, friction or resonance and responded instantly and faithfully to the tide raising forces, the amplitude H of any tidal constituent would be equal to that of its corresponding tide raising force constituent. However, this is far from being the case; each place will have its own series of Hs, quite unique to itself, and these can only be found by analysing a series of observations taken at it. This is the reason why the amplitudes F of the various tide raising force constituents are not needed in tidal analysis.

It has been found, however, that the amplitude H of a particular tidal constituent at a particular place does vary slowly in direct proportion to the theoretical nodal factor f. Thus the amplitude of a tidal constituent obtained from an analysis is fH.

The factor f may be looked up in the *Tide Tables*, for the time of the observation, and divided into fH to give the tidal amplitude constant H.

c. The expression for a tidal constituent

Every tidal constituent may be expressed in the form

$$h = fH \cos [(E + u) - g]$$

where h = Height above or below the x axis, which is mean sea level
f = Nodal factor
H = The amplitude constant } These two form the tidal constants for
g = The phase lag constant } the place.
(E + u) = The phase of the theoretical tide raising force at Greenwich; it increases at a rate n°/hour, where n is its speed.

d. Obtaining tidal constants by harmonic analysis

Many methods of harmonic analysis have been devised for use in tidal work. Most are based on the principles outlined above. Almost all use sets of multipliers similar to those referred to in Section **10a**(i) above, to isolate the various groups of tidal constituents. Some are more convenient to use, inherently more accurate, and involve less computational labour than others. The *Admiralty Semi-Graphic Method of Harmonic Tidal Analysis* (*over a period of one month*), which is published as *Admiralty Tidal Handbook No.* 1, will enable the hydrographic surveyor to obtain a very reasonable set of tidal constants from a series of observations spread over a lunar month. It has been especially devised to make the best use of all the observations available with a minimum amount of computation; perhaps its greatest advantage over other methods is that it enables the surveyor to make full use of his experience, common sense and judgement. Full instructions on the method are contained in the handbook. *Admiralty Tidal Handbook No.* 3, which again contains full working instructions, is designed to be used for the analysis of observations taken over a short period of 24 hours or so.

(i) Errors in harmonic analysis. It is important to realise that no method of tidal analysis yet devised for use in the field is precise, in the sense that it will break down the actual tidal movements into a series of pure cosine waveforms in all circumstances. If shallow water distortions did not exist, and the weather was always settled and calm, the problem would be relatively simple. However, shallow water distortions do exist, and the weather seldom is settled and calm, and these factors often complicate the tidal curve so much that it is extremely difficult to handle it without accepting some error.

As an example, the Admiralty Semi-Graphic Method first of all splits the tide up into three groups, or species of constituents, diurnal, semi-diurnal and quarter-diurnal. Each group contains no contaminating contributions from any of the others. However, if third-diurnal (eight hour period) harmonics are present in the tide, they will contaminate the diurnal constituents; and if sixth-diurnal (four hour period) harmonics are present they will contaminate the semi-diurnal constituents.

Where the shallow water effects are appreciable, these third and sixth-diurnal constituents may have an amplitude about 0·01 that of M_2, i.e. if the amplitude of M_2 was 10 feet they might together cause it to be in error by about 0·2 feet. Where the shallow water effects are really large no simple method of analysis will provide a satisfactory solution.

It is these inherent errors in the processes of harmonic analysis, together with the quite unpredictable effects of wind and weather, that make it so necessary for the hydrographic surveyor to observe the rise and fall of the tide on a gauge or pole whilst he is sounding.

13. Tidal Prediction

a. Principles; the tide predicting machine

Suppose that the surveyor in the field has obtained the values of Mean Sea Level and the constants for the tidal constituents M_2, S_2, K_1 and O_1, and wishes to use them to predict the tide for some days ahead.* Imagine that he has nothing to help him do this except the *Tide Tables* and Section **12** above. He might construct and use a machine similar to the one illustrated in Fig. 2–29.

This machine has been set for 0001 on 6th May 1966, and the recording drum

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* Predictions based on these four constituents alone will not, of course, be very good, since they will not take into account several factors which are by no means negligible. But see c below.

A SIMPLE TIDE-PREDICTING MACHINE

Note: The recording drum and the four Constituent wheels are driven by suitable gearing from the main drive, at the various speeds indicated. The crossheads can move up and down, but not sideways.

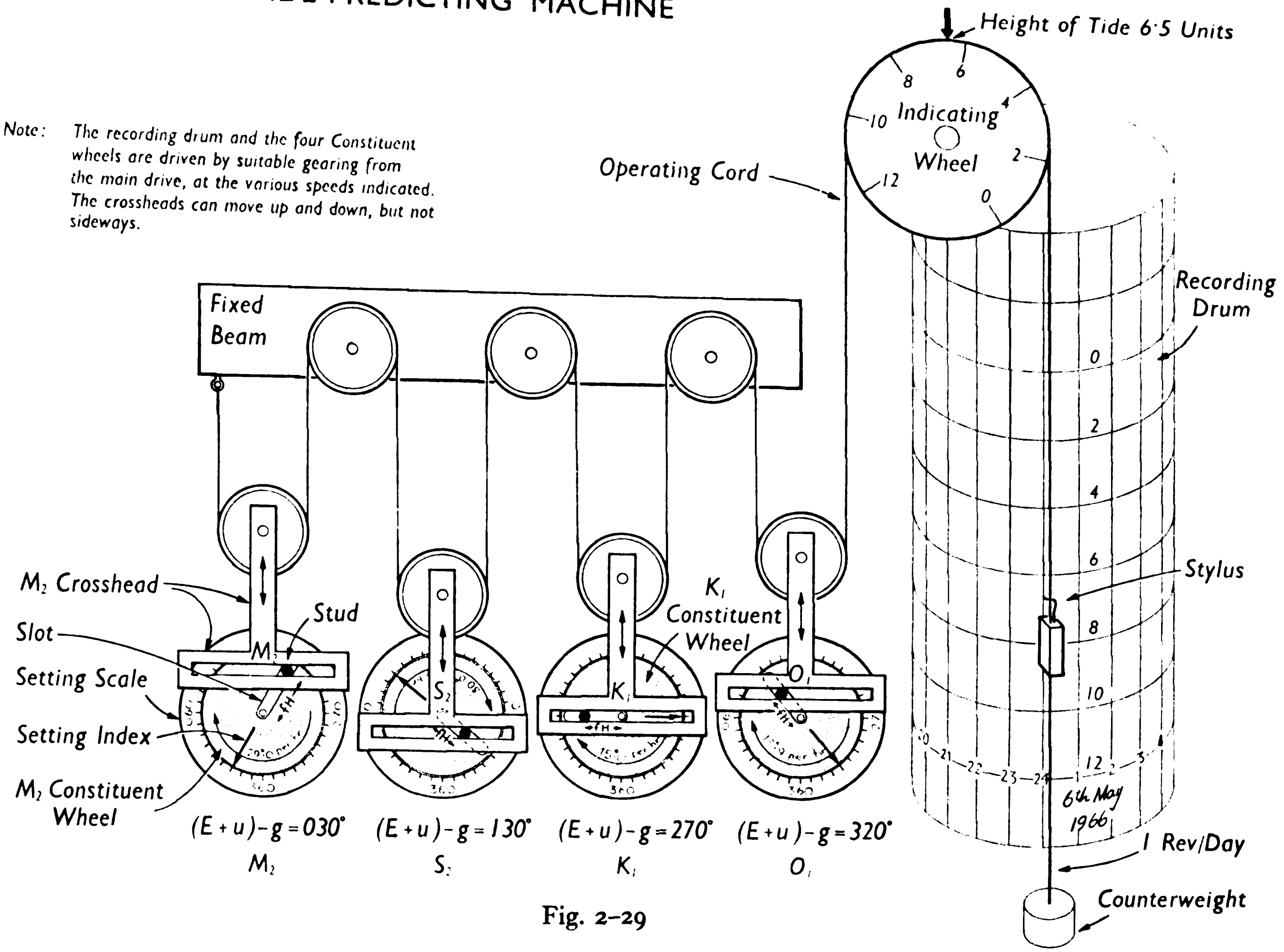

Fig. 2–29

indicates this time. Consider the unit labelled M_2, at the left hand side of the diagram. The constituent wheel will rotate clockwise at a speed of 29°·0/hour* (the speed of M_2) when the machine is switched on. This wheel is a tight friction fit on its driving shaft and may be set by hand to the value of $(E + u) - g$ at any time; in this case $(E + u)$ for M_2 at 0001 G.M.T. on 6th May 1966 is found from *Table VIII* of the *Tide Tables* to be 336°; the phase lag g for the place is 306°, and therefore the setting index must be set to 030° on the setting scale. Note that this procedure automatically produces predictions in the same local or zone time as that for which the phase lag g was calculated by analysis. If the machine is now started the phase of the constituent M_2 will be indicated on this dial for any time shown on the recording drum. The stud may be moved in the slot and locked in any position. Its radial distance from the centre of the constituent wheel must be set to fH; in this case f for M_2 on 6th May is found from the tide tables to be 0·98; if the amplitude constant H were 5·0 units, the stud would have to be set at a radius of $5{\cdot}0 \times 0{\cdot}98 = 4{\cdot}9$ units. This stud works in the slide of the crosshead, which can move vertically, but not sideways. As the M_2 constituent wheel rotates the vertical motion imparted by the stud to the crosshead will be of a simple harmonic nature, and may be expressed by the formula

$$h = fH \cos([E + u] - g).$$

This expression is of course that for the tidal constituent of M_2 referred to in Section **12c** above. If the M_2 crosshead were attached directly to the stylus the trace on the recording drum would be that of the tide caused by M_2.

The three other constituent wheels, S_2, K_1 and O_1, are set in the same way as that for M_2, using appropriate values of $(E + u)$ and f obtained from the tide tables, and their own constants; their settings in this case are shown in the figure. They operate their crossheads in the same way as the M_2 wheel.

The motions of the four crossheads are added together by the operating cord and the system of pulley wheels, so that the indicating wheel shows the height of the tide at any time, and the stylus draws a predicted tidal curve on the record paper.

Before the constituent wheels are adjusted the height of Mean Sea Level above datum must be set on the indicating wheel and recorder. To do this all the constituent wheels are set to 090° or 270° (since cos 90° = 0 their constituents will then be zero) and the indicating wheel and stylus are then adjusted by hand to the height of M.S.L. above datum; once this has been done all readings will automatically be referred to datum.

Note that the four constituent wheels rotate at awkwardly different speeds. To obtain these various speeds from a common drive is one of the most difficult problems in the design of a tide predicting machine.

All tide predicting machines operate on the principles set out above. Portable machines usually handle up to about 10 constituents, and produce very reasonable results in most circumstances. Large fixed machines may well handle over 100 constituents. The trend in modern tidal institutes is towards the replacement of mechanical machines by electronic computers, which do not suffer from backlash and friction, and can be made to work more flexibly and much faster.

b. Calculating the height of the tide at any time, using tidal constants

Suppose that the surveyor knows the height of M.S.L. above datum and the constants for M_2, S_2, K_1 and O_1, and wishes to calculate the height of the tide at 1500 ship time on 6th May 1966. The ship is keeping zone −8 time, but the constants are quoted with reference to zone −7.

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* A better value would of course be 28°·984/hour. This value is used here for simplicity.

The calculation may be carried out as follows:

Given:

CONSTANTS. ZONE −7

	M_2	S_2	K_1	O_1	
g	312°	024°	292°	281°	M.S.L. (average) 4·8 ft
H	2·2 ft	1·2 ft	0·6 ft	0·4 ft	Seasonal corrn. +0·1 ft
Speed of constituent	28°·98/hr	30°·00/hr	15°·04/hr	13°·94/hr	M.S.L. (6th May) 4·9 ft

Since the ship is keeping zone −8 time and the constants are quoted with reference to zone −7, a prediction made for 1400 'constant' time will be correct for 1500 ship time.

The computation may be set out in the form of a table:

	M_2	S_2	K_1	O_1	REMARKS
(E + u) at 0001 G.M.T. 6th May	336°	360°	127°	213°	From *A.T.T., Table VIII*
g	312°	024°	292°	281°	From table above
(E + u)−g at 0001 Zone −7	024°	336°	195°	292°	Subtract. Note automatic conversion to Zone −7
Increment for 14 hours	046°	060°	211°	195°	(Constituent speed × 14) in each case
(E + u)−g at 1400 Zone −7	070°	036°	046°	127°	Add
Cos [(E + u)−g] at 1400	+0·34	+0·81	+0·69	−0·60	Watch the signs
f for 6th May	0·98	1·00	1·07	1·12	From *A.T.T., Table VIII*
fH	2·2	1·2	0·6	0·4	
fH cos [E + u)−g] at 1400	+0·7	+1·0	+0·4	−0·2	

Height of tide at 1400 (Z−7) = 4·9 + 0·7 + 1·0 + 0·4−0·2 = 6·8 feet.

Note that this calculation is of the same type as that which has been solved mechanically by the tide predicting machine in **a** above. The summation of the four constituent values at 1400 may be carried out graphically, if desired, by drawing vectors on a mooring board.

The use of four constituents only will not produce a very good prediction, since M_2, S_2, K_1 and O_1 are all in fact modulated by other frequencies, some of which are by no means negligible. They are used here merely to demonstrate the principles involved and for the sake of simplicity.

A very good prediction will be obtained if all 10 constituents tabulated in *Admiralty Tide Tables Table VIII* are used. Alternatively, compound constituents for M_2, S_2, K_1 and O_1 may be derived from the *Tidal Angles* and *Factors* listed in *Table VII* of the *Tide Tables*, and used in the way described in **c** below to obtain very reasonable predictions.

c. Compound constituents of M_2, S_2, K_1 and O_1; their use in tidal prediction; tidal angles and factors; Table VII of Admiralty Tide Tables

It has been seen in Section **11a**(i) above that the tidal constituent M_2 must be modulated by several other frequencies, to allow properly for the motion of the actual moon. Suppose that these modulations are made; then the resultant compound constituent of M_2, which consists of the basic M_2 constituent and all the modulating constituents, could be tabulated for each day of each year. These tabulations might conveniently take the form of the (E + u) of the compound constituent, and a factor which converted the amplitude constant H of M_2 for any place into that of the compound constituent for M_2, allowing for the nodal factor f in the process.

If the same procedure were repeated for the constituents S_2, K_1 and O_1, four compound constituents would be produced which would allow very reasonably for the motions of the actual moon and the actual sun. These constituents could then be used on a tide prediction machine to produce predictions; they could also be used in the way described in **b** above to produce an answer comparable in accuracy with that obtained by the use of 10 constituents.

The *Tidal Angles* and *Factors*, tabulated for each day of the year in *Table VII* of the *Admiralty Tide Tables Vols. II and III*, enable the surveyor to calculate these compound constituents.

In each case, the tidal factor converts the amplitude constant H for any place into the constant for the compound constituent, allowing for the nodal factor f. For example, suppose that the amplitude constant H of M_2 for a place is 4·2 feet, and that on 6th May 1966 the tidal factor (from *Table VII*) is 1·06; then the amplitude constant H of the compound constituent M_2 is $4{\cdot}2 \times 1{\cdot}06 = 4{\cdot}4$ feet. Note that the tidal factor changes appreciably each day, and in this case to 1·02 on 7th May. This change does not take place suddenly at 0001 on 7th, and for this reason the use of these tidal factors must introduce some error, which could be lessened by tabulating them at more frequent intervals. For the purposes for which *Table VII* was devised this error is acceptable (see **d** below). If the surveyor cannot accept it he may interpolate between the tabulated values; thus in the example above a factor of 1·04 would produce an accurate prediction for 1200/6th, and one of 1·03 might be used for 1800.

The *Tidal Angle* for M_2, tabulated for each day of the year in *Table VII*, is (360° − (E + u) of the compound constituent of M_2).* If the compound (E + u) for M_2 is extracted from it, it will be found to differ from the value of the simple (E + u) for M_2 tabulated in *Table VIII* by an amount which varies from day to day, and which may be anything up to 20° or 25°. Thus the speed of the compound constituent is neither equal to that of M_2, nor constant. It may be found in the following way from *Table VII*.

MAY 1966—VALUES FOR M_2

	TIDAL ANGLES (*Table VII*)	EQUIVALENT (E + u)	DAILY ANGULAR CHANGE	HOURLY SPEED
6th	035°	325°	695°	28°·96
7th	060°	300°	696°	29°·00
8th	084°	276°	697°	29°·04
9th	107°	253°		

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* The introduction of an apparently unnecessary 360° into this expression may seem odd. The reason for doing this is given in **d** below.

For the purposes for which *Table VII* was devised speeds of 29°/hour for the compound constituents of M_2 and S_2, and $14\frac{1}{2}$°/hour for those of K_1 and O_1, produce results which are sufficiently free from error. If the surveyor cannot accept these errors he may calculate his own 'speeds for the day' as described above. The fact that the speed of any compound constituent is changing continuously and not in steps at 0001 each day, may be neglected in all circumstances, without introducing any measurable error.

Suppose that the surveyor is satisfied concerning the use of compound constituents* and wishes to obtain them for M_2, S_2, K_1 or O_1. The procedure is as follows:

(1) Look up the constants for the place, g and H, in the usual way in the tide tables.

(2) Obtain the tidal angles for M_2, S_2, K_1 and O_1 from *Table VII* for the day in question. Subtract each angle from 360° to obtain the (E + u) of the compound constituent concerned.

(3) Obtain the 'speed for the day' for each constituent in the way described above, or accept speeds of 29°/hour for M_2 and S_2 and $14\frac{1}{2}$°/hour for K_1 and O_1. If in doubt use the first method.

(4) Obtain the tidal factors for the day in question from *Table VII.*

The compound [(E + u)−g]'s may then be used in the ways set out in **a** and **b** above; the expression fH referred to in these sections must be replaced by (*Tidal Factor* × H).

d. Prediction using Admiralty Tidal Prediction Form (HD289) and Table VII of the Admiralty Tide Tables

Admiralty Tidal Prediction Form (*HD* 289) may be used in conjunction with *Table VII* of the *Admiralty Tide Tables* to produce a very reasonable predicted tidal curve for any day, using the compound constituents of M_2, S_2, K_1 and O_1 referred to in **c** above. Full instructions concerning the use of the form are given on it.

The surveyor who has read this section may well wonder, when using this form, at certain apparent discrepancies between the principles behind its use and those described here. These may be explained as follows:

(1) The form was devised in 1947 for use by the surveyor in the field. It made no attempt to explain the principles involved, but concentrated on enabling him to obtain the correct result by rote, with the least possible amount of computation.

Table VII of the *Admiralty Tide Tables* was devised at the same time as the form, and was intended to be used solely with it. It was not envisaged in 1947 that surveyors would extract (E + u) for the compound constituents from this table.

(2) It has been seen above that the phase of a tidal constituent is expressed by the equation Phase = (E + u)−g. The authors of *Form HD* 289 decided that the surveyor would find it better (and less liable to error) if he added the 'phase lag', rather than subtracting it. They therefore tabulated quantities 360°−(E + u) in *Table VII* of the *Admiralty Tide Tables*, calling them 'Tidal Angles', and instructed the surveyor to add the phase lag g to these angles, to obtain the 'phase' of the compound constituent. The resulting 'phase' is in fact equal to 360°−(the real (E + u) referred to elsewhere in this manual).

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* They may safely be used in all but the most rigorous tidal work. Recent investigations indicate that the compound constituents of M_2, S_2, K_1 and O_1 between them allow for the effects of 26 constituents.

(3) As an example consider the figures for M_2 given in the directions for using the form. They are as follows:

g	158°
Tidal angle	101°
Sum (apparent phase)	259°

The true values, relying on the basic principles set out above, are as follows:

g	158°	
Compound (E + u)	259°	= 360° − tidal angle
True phase = Compound (E + u) − g	101°	= 360° − apparent phase

It is a coincidence that the tidal angle and the true phase have the same value in this case.

14. Symbols used in Tidal Work

The following lists give the symbols most frequently used in tidal work, with brief descriptions:

a. General

A_0	The height of M.S.L. above an arbitrary datum differing from chart datum or the zero the tide gauge. It is generally associated with old work which cannot be properly connected to modern levelling systems.	
A	Used in harmonic analysis, where $A = R \cos \varphi$	See Section **10a(i)**.
B	Used in harmonic analysis, where $B = R \sin \varphi$	
E	The phase at Greenwich of a constituent of the tide raising force, neglecting nodal corrections.	
f	The nodal factor, by which the Hs of all lunar constituents must be multiplied to allow for the nodal variations in the moon's orbit. It is tabulated in *Table VIII* of *Admiralty Tide Tables Vols. II and III.*	
F	The amplitude of a tide raising force constituent. It is not needed in practical tidal work.	
g	The phase lag of a tidal constituent at a particular place, relative to (E + u). It is a constant for a given place. The local time for which it has been calculated must be specified.	
h	Used in tidal equations to refer to the height of the tide.	
H	The amplitude constant for a given place.	
H.A.T.	Highest Astronomical Tide, a level reached about once or twice every four to five years.	
L.A.T.	Lowest Astronomical Tide, a level reached about once or twice every four to five years.	
M.H.W.S.	Mean high water springs	Symbols used when the tide is mainly semi-diurnal. Definitions will be found in Sections **5c** and **5d** of this chapter
M.L.W.S.	Mean low water springs	
M.H.W.N.	Mean high water neaps	
M.L.W.N.	Mean low water neaps	
M.H.H.W.	Mean higher high water	Symbols used when the tide has a large diurnal component. Definitions will be found in Section **5e** of this chapter.
M.L.L.W.	Mean lower low water	
M.L.H.W.	Mean lower high water	
M.H.L.W.	Mean higher low water	
M.S.L.	Mean sea level, the mean of many hourly heights of tide.	
M.T.L.	Mean tide level, the mean of high water and low water.	

M.L.	Mean level. This may refer to M.S.L. or M.T.L. It should not be used.
n	The speed of a tidal constituent. It is a measure of frequency.
R	Used in tidal formulae to denote the amplitude of a harmonic term. Used in general navigational practice to denote the range of the tide, which is twice the amplitude. Care must be taken in its use to avoid confusion.
S_0	The height of M.S.L. above the zero of a tide gauge during a period covered by a tidal analysis.
t	Used in tidal formulae, where it denotes time in hours.
Tidal Angle	Given in *Table VII* of *Admiralty Tide Tables, Vols. II and III*, for M_2, S_2, K_1 and O_1. It is a quantity $360^\circ-(E+u)$ for the compound constituent concerned. See section 13**d**.
Tidal Factor	Given in *Table VII* of *Admiralty Tide Tables, Vols. II and III.* It converts the H of the constituent concerned into that of the equivalent compound constituent, allowing for nodal corrections. See section **13d**.
u	The nodal phase correction. It must be added to the E of any tide raising force or tidal constituent. Quantities (E + u) for the main tidal constituents are tabulated in *Table VIII* of *Admiralty Tide Tables, Vols. II and III.*
Z_0	The height of M.S.L. above chart datum during a period covered by a tidal analysis; in this context Z_0 has not been corrected for seasonal changes. Where it appears in *Admiralty Tide Tables*, Z_0 is the best value for M.S.L. that can be obtained and seasonal changes have been corrected for; it is then identical with Z_{00}.
Z_{00}	The best value for M.S.L. that can be obtained. Seasonal variations have been removed from it. An ideal value of Z_{00} could only be obtained from the analysis of many years' (over 19) continuous observations.

b. Tidal constituents

(i) Lunar

M_2	The semi-diurnal constituent of a fictitious moon, which moves in a circular orbit in the plane of the equator.
N_2 L_2	Modulate M_2, converting the circular orbit of the fictitious moon into an elliptical one in the plane of the equator.
ν_2 λ_2 μ_2 S_2	Modulate M_2, allowing for the fact that the real moon's orbit is not elliptical, but pear shaped, since the sun attracts it more at new moon than at full moon. This S_2 is not the main semi-diurnal constituent of the mean sun.
K_2	Modulates M_2, converting the orbit from the plane of the equator into the mean plane of the real moon.
K_1 O_1	The diurnal constituents of a fictitious moon which has a fixed circular orbit in the mean plane of the real moon.
J_1 M_1 Q_1	Modulate K_1 and O_1, allowing for the fact that the moon's orbit is not circular, but elliptical. M_1 is the sum of two constituents, which cannot easily be separated.
M_f M_m	'Long Period' lunar constituents, with periods of about a fortnight and one month respectively. They have very small amplitudes, and are often masked by meteorological and shallow water effects.

(ii) Solar

S_2	The semi-diurnal constituent of the mean sun, which moves in a circular orbit in the plane of the equator.
T_2	Modulates S_2, allowing for the fact that the sun's orbit is an ellipse. Another constituent, which operates with T_2, is so small that it is not named and is neglected.

K_2	Modulates S_2, allowing for the fact that the sun's orbit is in the plane of the ecliptic. Another constituent which operates with it is so small that it is unnamed and neglected. This K_2 has the same speed as the moon's K_2, and the two are combined.
K_1 P_1	The diurnal constituents of a fictitious sun which has a circular orbit in the plane of the ecliptic. This K_1 has the same speed as the moon's K_1, and the two are combined.
S_{sa} S_a	Long period solar constituents, with periods of about six months and one year respectively. They have very small amplitudes, and in practice cannot usually be distinguished from changes in M.S.L. caused by prevailing winds and monsoons.

(iii) Shallow water

M_4	The second harmonic of M_2, with twice its speed.
MS_4	A quarter diurnal constituent produced from M_2 and S_2. It has a speed equal to the sum of their speeds.

There are many other shallow water constituents. These two only have been listed since they alone are tabulated in *Table VIII* of the *Admiralty Tide Tables, Vols. II and III.*

Part 2 Tidal Streams

15. Introduction

Although it is possible to navigate with safety in areas where nothing is known about the tidal streams, the mariner's task will be made much easier if he has reliable information concerning the horizontal movement of the water through which his ship is sailing.

For this reason the surveyor must observe and measure the horizontal movement of the water in his survey area. Although this may appear to be a simple task at first sight, it will, in fact, require the application of much careful thought and labour, if the results are to be reliable. Proper observations cannot be carried out in the odd spare moments which the surveyor may find; intermittent and unrelated observations will always be better than no observations at all, but a proper investigation of the properties of tidal streams and currents in an area will generally require the deployment of the greater part of the resources of a surveying vessel.

Even though the greatest care and ingenuity are applied to the observation and analysis of horizontal water movements, the resulting tidal stream predictions (which are what the mariner needs) can never compare in reliability with predictions of the vertical movement of the tide. Random errors of observation are usually very large compared with the quantities which are being measured; it is not easy, in the limited time which can be given to the observation of tidal streams, to obtain sufficient observations to reduce these errors appreciably. Only very rarely will it be possible to obtain a series of observations covering a period of a lunar month—a comparatively easy task so far as the tides are concerned. For this reason the second best methods used for tidal analysis become the only methods that can be used for tidal stream analysis, and the results inevitably suffer.

In what follows the nature of tidal streams and currents will be discussed, the difficulties of observation and analysis will be set out, and various ways of overcoming these difficulties will be described.

a. Terms used in tidal stream work

Mariners from different countries do not all use the same terminology when they refer to the horizontal movement of the water. It is therefore important that the terms used in the Surveying Service of the Royal Navy should be explained.

(i) Tidal stream.* Imagine a body of water on the surface of a fictitious earth, where the tide generating forces are the only outside influence. If there is a tidal stream (and there may not be) a particle of water will move horizontally away from its starting point with a velocity and in a direction which will vary with time. It may or may not trace out quite a complex track, but it will always return to its starting point† after one tidal stream cycle, which will occupy about 12½ hours if the streams are semi-diurnal, or about 25 hours if they are diurnal.

The direction and rate of the tidal stream at any time may well vary between the water surface and sea bed; it is therefore very important that information concerning it should state quite clearly the depth at which observations were obtained. The surveyor usually observes the average tidal stream between the surface and a certain depth, up to about 30 feet, since this is what will affect a typical vessel.

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* In some countries the term 'Tidal current' is used.

† In theory this is not quite true, since the forces which cause tidal streams are themselves changing slowly with time, e.g. from springs to neaps, and perigee to apogee. In practice the surveyor, who can only make a relatively short series of observations, cannot separate these changes from meteorological effects and current.

(ii) Tidal flow. Tidal flow is the movement of the water actually experienced in a given area. It is usually expressed as a rate in a certain direction, e.g. 1·4 knots towards 159°; it will vary with time. Tidal flow is made up of the true tidal stream and several other components, and it may well contain quite large random errors of observation.

The art of observing and analysing horizontal water movement lies in splitting up the observed tidal flow into its component parts, and removing the random errors.

(iii) Residual motion. Where a comparatively short series of observations has been obtained, the residual motion converts the tidal stream into the tidal flow. It is usually expressed as a rate in a certain direction. It will not vary over the period covered by the observations. Residual motion will contain the true current, if there is one; but it will also contain relatively short period 'currents' caused by meteorological and other effects. It may well change from day to day.

(iv) Current. The true current cannot be obtained by the surveyor in the field, unless he observes the tidal flow for at least 29 days. It is obtained in the office by considering the residual motions of several sets of observations obtained at or near the same place. Current should not change from day to day, but it may well change from month to month.

(v) Predicted tidal stream. The tidal stream predictions set out on Admiralty charts and in the *Admiralty Tide Tables* always refer to the pure tidal stream defined in (i) above, unless there is a note to the contrary.

16. The Nature of Tidal Streams

The primary causes of tidal streams are the attractive forces of the moon and sun, which also produce the tides. In theory these forces produce tidal streams first, and the vertical movement of the tides as a secondary effect. In practice it is impossible to distinguish between cause and effect.

Present day tidal theory and analysis produces predictions which compare quite well with actual observations; discrepancies between the two can usually be explained, if not always allowed for. As will be seen below the best modern methods will produce only very approximate tidal stream predictions, provided these streams are predominantly semi-diurnal; where they have a measureable degree of diurnal inequality they are extremely difficult to handle, and predictions will probably contain large and variable errors.

The reasons for this state of affairs can be deduced by common sense.

The tides can only move up or down; the mariner is interested in their height, and the surveyor therefore merely has to measure this changing height and then analyse his observations. Random errors of observation can be reduced by using a well designed tide gauge over a long period.

Tidal streams may appear to be similar, but are in fact quite different. The mariner is not interested in the horizontal distance that a particle of water has moved in a given time; he wants to know the direction and rate of the tidal stream. Thus, whereas tidal theory deals in simple linear quantities, tidal stream theory must handle velocities and directions. The tide can only rise or fall; the tidal stream at a given spot can in extreme cases be travelling in one direction on the surface and in the opposite direction near the sea bed. The tidal stream may flow backwards and forwards, its rate varying between maxima in either direction; or its direction may change continuously, its rate remaining fairly constant; or its behaviour may be any combination of these two relatively simple motions. The characteristics of a tidal stream may be semi-diurnal, diurnal, or a mixture of both;

if they are a mixture they will almost certainly change as the sun and moon move in declination. It is quite possible to find diurnal tidal streams associated with semi-diurnal tides, and vice versa. Tides are not directly affected by the rotation of the earth; tidal streams are affected.

To unravel this very complicated skein the surveyor has until quite recently had to rely upon observations obtained over very short periods of time (it has been most unusual for more than two series of 25 hourly observations to be taken at any one spot), from a vessel at anchor in the open sea. As may be imagined, with weak streams he was quite likely to be observing the movement of his vessel about her anchor rather than the stream.

Modern electronic fixing aids will enable him to obtain more reliable observations; but until some way is found of obtaining these observations reliably over a long period (29 days at least) without tieing down a surveying vessel, progress will probably be slow. An automatic tidal flow meter that could be left in a given spot to measure and average out the rate and direction of the stream at 10 different depths once an hour for perhaps a week, without attention, would be a great asset. In the absence of such a machine the surveyor must make the best use of the equipment which is available to him.

a. Tidal streams in the deep oceans; rotary streams caused by the tide generating forces

Mariners sometimes think that tidal streams exist only in the relatively shallow waters of the continental shelves and enclosed seas. This is not so. Tidal streams, even though they may be very weak, must ebb and flow wherever there is water. In the deep oceans the mariner is not usually concerned with them, since his methods of fixing are not precise enough to detect them. The advent of modern electronic fixing aids is enabling the surveyor to detect them in places where before they have been deemed to be non-existent; for instance, tidal streams with a maximum rate of one knot have been observed superimposed on the Gulf Stream between Scotland and the Faroe Islands.

Suppose that the earth is completely covered with water, and that the sun and moon remain in the plane of the equator at fixed distances, i.e. that the constituents S_2 and M_2 only are to be considered. Then on the equator the tidal streams will flow due east and due west. Elsewhere they will rotate, clockwise in the northern hemisphere and anti-clockwise in the southern hemisphere. A particle of water will move in an elliptical path relative to the surface of the earth; its velocity and direction will vary from moment to moment. Near the equator the ellipse will be very elongated (on the equator it will become so elongated that it turns into a straight line); in higher latitudes the ellipse will become fatter and fatter, until at each pole it will turn into a circle.

As soon as the sun or the moon moves out of the plane of the equator, the tidal streams will become rotary, even on the equator. The simple elliptical movement described above will be 'modulated' by many other 'tidal stream constituents' and the path traced out by a particle of water will probably become very complex indeed.

Since the earth is not completely covered with water, and since several other factors besides the tide generating forces have a strong influence on the real tidal streams, there will be no point in trying to develop the pure theory set out above too far.

The important point that the surveyor should remember is that tidal streams will of their very nature tend to be rotary. They will only flow back and forth in opposite directions when they are allowed to do nothing else, being restricted by the land or by shoals.

b. Rotary streams caused by the coriolis effect

In Fig. 2–30 the earth is rotating on its axis from west to east at an angular velocity of 15°/hour. At the equator the water, although stationary relative to the earth, will be moving east at a linear speed of 900 miles/hour. At the poles its linear speed will be zero, and it will merely be rotating about the polar axis. At a point *A*, its linear speed will be 900 (cos Lat. *A*) miles/hour.

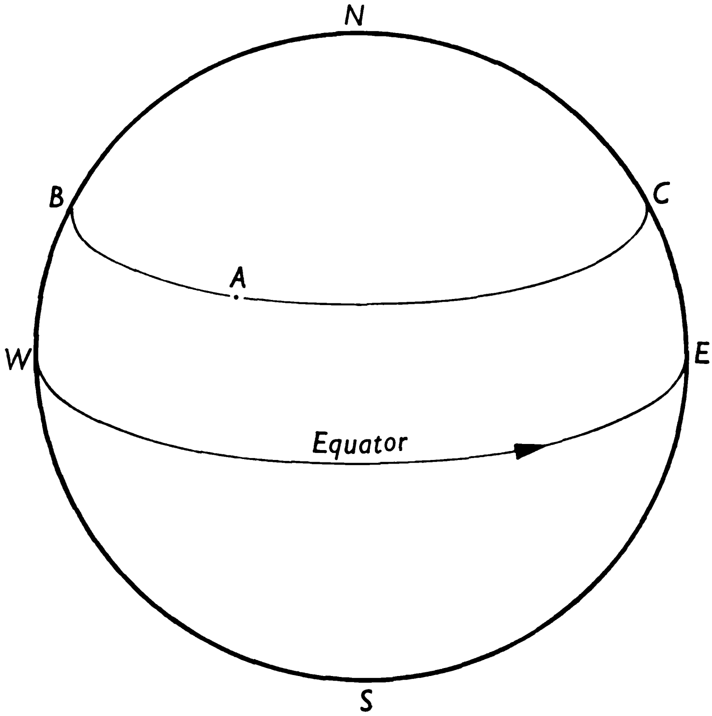

Fig. 2–30

Suppose that a particle of water at *A* starts to move in an easterly direction relative to the surface of the earth, under the influence of the forces which produce tidal streams. It will find itself moving too fast for its latitude, and will immediately start moving south, in an endeavour to reach a latitude where it will once more be in a state of equilibrium.* The amount of the deflection will depend on its speed and its latitude; the greater these are the greater will be the deflection.

Suppose now that the forces producing the tidal stream cease, but that the particle maintains its small southerly velocity due to its inertia. It will immediately find itself proceeding into lower latitudes, where the sea-bed is moving eastward faster than it is. It will therefore be deflected to the westward. When the tidal stream forces impart a westward velocity to it, it will veer to the north, and when they cease the northerly component of its motion will tend to carry it eastwards.

Thus even though the forces producing the tidal stream act due east and west (as they may in very special circumstances), the particles of water will still tend to move in an ellipse in a clockwise direction. The stronger the original east–west velocity the more nearly will this ellipse approach the shape of a circle.

In the northern hemisphere the deflection caused by the coriolis effect is always to the right of the original motion, and the tidal streams will tend to rotate in a clockwise direction on this account. In the southern hemisphere the deflection is to the left, and the rotation is anti-clockwise. In both cases the coriolis effect tends to amplify the natural tendency of the stream to rotate in response to the tide generating forces.

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* Put another way, the increase of speed increases the centrifugal force acting on the particle, and reduces its weight. It may either become airborne or move south, towards a point where its decreased weight fits in. It does the latter.

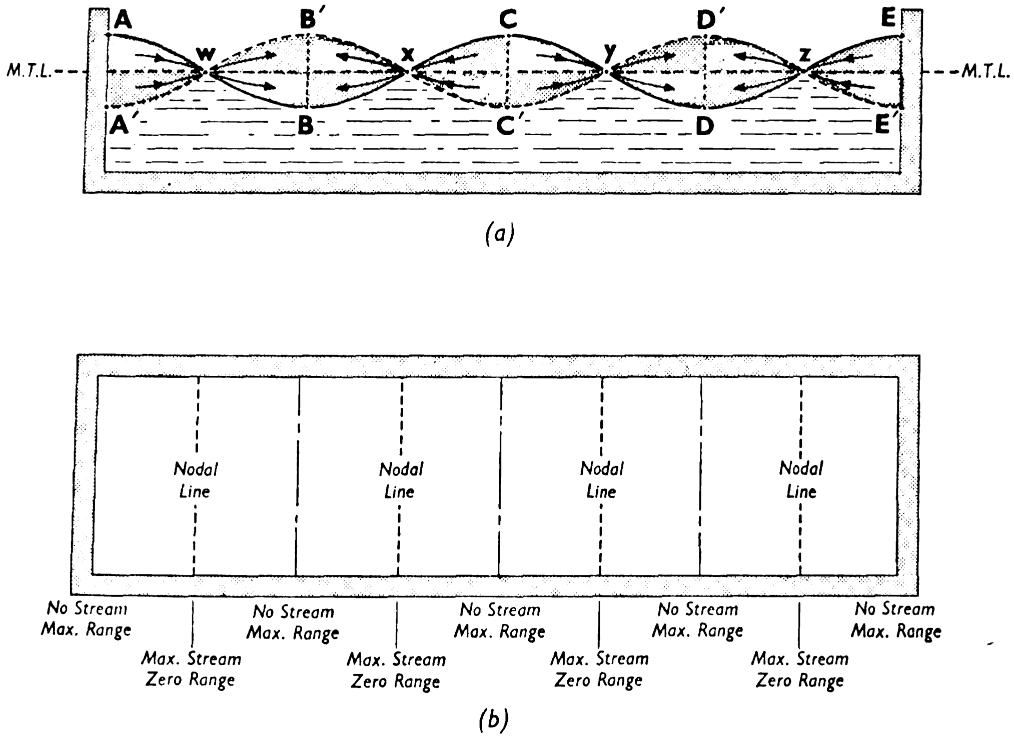

Fig. 2–31

c. Resonance; amphidromic lines and points

Figs. 2–31(*a*) and (*b*) show elevation and plan views of a narrow reactangular swimming bath half full of water; it is in the northern hemisphere and is exactly two wavelengths long. When the water is undisturbed its level is indicated by the pecked line labelled M.T.L. in (*a*).

Suppose that a pure sinusoidal standing wave* is generated by some means in the bath, and that the force generating it is just sufficient to overcome friction, so that although the system is resonant the train of waves maintains a constant amplitude. Suppose that the period of this wave is t seconds, and that at the first instant of observation the entire water surface is flat and coincides with M.T.L. Then at a time $t/4$ seconds later the shape of the water surface will be that of the firm curve *ABCDE*, and the volume of water which has been transported in this time will be equivalent to the areas coloured in red. At a time $t/4$ seconds later still the surface will again be flat, coinciding with M.T.L.; $t/4$ seconds later still it will take the form of the pecked curve *A′B′C′D′E′*, and the change from the M.T.L. surface will be equivalent to the areas coloured blue. The red and blue areas indicate the maximum vertical displacement of the water at various points from M.T.L.; these maxima in each direction occur at instants which are separated by half the period of the wave.

Several things are apparent immediately concerning the vertical movement of this artificial tidal wave:

(1) Along certain lines, labelled w, x, y and z in Fig. 2–31(*a*), and shown pecked in Fig. 2–31(*b*), the tide does not rise or fall at all; it remains always at M.T.L.;

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* Note that this wave is not 'travelling' along the bath. It is forming, collapsing to a flat surface, and re-forming with opposite phase, all in the same place.

these lines are called nodal, or amphidromic lines, and are separated by distances of half a wavelength.

(2) Along lines half-way between the nodal lines the range of the tide is a maximum. These lines are labelled *AA'*, *BB'*, etc., in Fig. 2–31(*a*); they are known as anti-nodal lines.

(3) Between *AA'* and *W* the phase of the tide will be the same at all points, i.e. high and low waters will occur at the same instant. Between *W* and *BB'* the phase of the tide will again be the same at all points, but low waters in this area will coincide with high waters between *AA'* and *W*. This pattern is repeated exactly between *CC'* and *DD'*, and its mirror image occurs between *BB'* and *CC'*, and *DD'* and *EE'*. The change over from zones of high water to zones of low water takes place along the nodal lines *w*, *x*, *y* and *z* where the range of the tide is zero.

Consider now how the tidal stream must behave. Suppose that the water surface at the instant of observation has the shape of the firm curve *ABCDE*, with humps at *A*, *C* and *E*, and hollows at *B* and *D*. A short time later it must have transformed itself into *A'B'C'D'E'*. This can only happen if the water flows horizontally in the directions indicated by the arrows. A great deal of water will have to flow through the bottlenecks at *w*, *x*, *y* and *z*, but there will be no flow at all at the antinodal lines *AA'*, *BB'*, etc.

If the arguments concerning the tide and tidal stream are combined, the following result is obtained:

(1) Nodal and anti-nodal lines will be formed; the distance between each pair of the same sort will be half a wavelength.

(2) Along the nodal lines the range of the tide will be zero, but the tidal streams will flow most strongly.

(3) Along the anti-nodal lines the range of the tide will be greatest, but there will be no tidal streams at all.

(4) The maximum rate of tidal stream will occur everywhere at half tide level, when the water surface is completely flat. The streams will turn at high and low water.

(5) At points separated by one wavelength, the instantaneous tide and tidal streams will be identical.

(i) Amphidromic points. Consider the part of Fig. 2–31(*a*) between the lines *AA'* and *BB'*. It has recently been high water between *AA'* and *w*, and the tidal stream is now flowing to the right, in the direction of the arrows, to transfer this high water to the region between *w* and *BB'*. Since the bath is in the northern hemisphere the coriolis force will deflect this stream to the right, out of the paper; the greatest amount of deflection will occur along the nodal line *w*, where the streams are strongest; there will be no deflection at all at *AA'* and *BB'*, since the tidal stream never flows at these places. If the nodal line is considered to be a seesaw the end nearest the reader will be tipped up, and the maximum amount of tip will occur when the water surface would otherwise have been quite flat at M.T.L. At this same instant the stream between *CC'* and *BB'* will be flowing to the left; the end of the nodal line *x* nearest the reader will therefore be tipped down. Line *y* will behave in the same way as line *w*, and line *z* will follow line *x*, both exactly.

Where before the M.T.L. surface was horizontal all over, it will now only be horizontal along the anti-nodal lines *AA'*, *BB'*, etc.; elsewhere it will be twisted. In this particular case the edge nearest the reader in Fig. 2–31(*a*) will be up at *w*, down at *x*, up at *y* and down at *z*. After half a period of the wave has elapsed these conditions will be reversed, as the streams will all be flowing the other way.

Four separate oscillations tranverse to the bath will be superimposed on the original one along its axis; the nodal lines *w*, *x*, *y* and *z* will be seesawing up and down about central pivots; the amplitude of their movements at both sides of the bath will of course be small compared with that of the original wave, and will depend on the magnitude of the coriolis force at the place concerned.

The result of all this is that the original nodal lines will shrink into nodal, or amphidromic points, which will lie on the axis of the bath. The tides will appear to rotate about these points.* Maximum streams will flow through the amphidromic points, where the water will always remain at the level of M.T.L. There will be no streams at all along the original anti-nodal lines *AA′*, *BB′*, etc., which will remain unaltered; along these lines the range of the tide will be greatest.

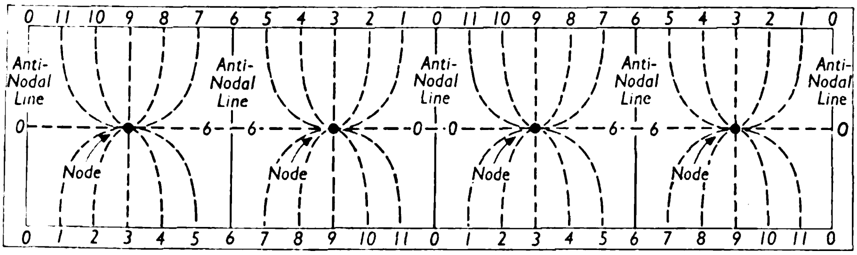

Fig. 2–32

Fig. 2–32 shows how the various wave crests will move about. The period of the original wave is here assumed to be 12 (tidal) hours. If at any instant high water occurs along the lines labelled 0, then one hour later it will have reached the lines labelled 1, and so on.

Note that there are four entirely separate systems, each rotating about its nodal or amphidromic point, and each separated from its neighbours by an anti-nodal line, across which no water moves.

An observer moving about the edge of the bath, and unable to see what was going on in the centre of it, would note the following phenomena:

(*a*) Two trains of tidal 'waves', one on each side of the bath, starting at the same time at opposite ends and proceeding in opposite directions. It might indeed well appear that one tidal 'wave' was proceeding around the edge of the bath in an anti-clockwise direction.

(*b*) The range of the tide would vary, being greatest at the anti-nodal lines, and least (though not zero) at points halfway between these lines.

(*c*) The tidal streams would appear to run back and forth parallel to the sides of the bath, alternatively towards and away from the anti-nodal lines. Maximum streams would run halfway between these lines, where the range of the tide was least, and at them it would be slack water all the time.

If the observer moved out into the bath, and made a tour of inspection, he would notice that, except along the anti-nodal lines, there was a transverse tidal stream superimposed on the longitudinal one which he had observed along the edges, causing the streams to be rotary. If he moved about in search of the spot where both the longitudinal and transverse streams were strongest, he would eventually find the four nodal points, and perhaps then discover that at these points the range of the tide was zero. Only then would he be able to begin to understand what was really going on.

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* The analogy with the mode of operation of an a.c. induction motor is very close. In this four coils at right angles to each other are energised in opposite pairs, and the phase difference between pairs is 90°. The resulting magnetic field rotates, carrying the armature round with it.

d. Amphidromic systems in practice

The amphidromic system described in **c** above is of the simplest possible form. In it the original wave has a pure sinusoidal form, the bath has a flat bottom and vertical sides, the whole system is resonant and is quite undisturbed by wind and weather.

None of these attributes is to be found in any body of water on the earth. The complexity of the tidal waveform, its variation with changing astronomical conditions, the varying depth of water and obstructions such as sandbanks and shoals, and changing meteorological conditions will all make amphidromic systems in practice much more complicated than the one described above.

The following major variations from the theoretical ideal may well be found in practice:

(1) A system will not be perfectly resonant, and the way in which it responds to the tide producing forces will almost certainly vary as these forces themselves change with varying astronomical conditions.

(2) The nodal points and anti-nodal lines may well move about as the sun and moon change their declination, right ascension and distance.

(3) The tidal streams will probably not reverse exactly at local high or low water. In extreme cases they may even change direction at half tide. Again there may well be weak streams running across the anti-nodal lines.

(4) The nodal points will almost certainly be displaced well to the left of the central line of a sea in the northern hemisphere,* when this is viewed from the open (oceanic) end. In extreme cases, e.g. the English Channel and Irish Sea, this displacement may be so great as to deposit the nodal points on dry land. This movement causes the range of the tide on the right hand side of a basin of water to be greater than that on the left hand side. Thus the tidal range on the French coast of the English Channel is greater than that on the English coast; in the North Sea the range on the English coast is greater than that on its eastern shores; the Welsh coast of the Irish Sea has a range greater than that found on the Irish side of the basin.

The complexities of an amphidromic system cannot be unravelled merely by observing the rise and fall of the tide at various places. Tidal stream observations must be available as well, and to be of very much use they must be taken over quite a long period, and in several carefully selected places.

For this reason the surveyor's tidal stream observations will not only assist the mariner, but also provide the tidal specialist with vital raw material.

17. Observing Tidal Streams

a. When to observe

An ideal set of tidal stream observations would consist of hourly values of the rate and direction of the tidal flow obtained over a period of at least one lunar month. This ideal is unlikely to be approached in general practice until a suitable automatic tidal flow meter becomes available.

So long as the observation of tidal streams requires the deployment of the greater part of the resources of a surveying vessel, it is not very likely that it will be possible to devote more than two or three days to it during the course of an original survey. The surveyor may well receive guidance on when and how to make his observations from the tidal specialists in the office. In the absence of such guidance he should proceed on the following lines:

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* Since the coriolis effect is involved here, the displacement ought to be to the right in the southern hemisphere. At the present time (1967) there is very little direct evidence in the southern hemisphere to support this theory, though it fits the observed facts well in northern latitudes.

(1) He should observe the tidal flow at hourly intervals for a period of at least 25 and preferably 50 hours, at a time when the streams are running most strongly. This will generally be when the range of the tide is greatest. It will always be better, if time is short, to devote whatever time is available to this series of observations in preference to that described below.

(2) If time is available he should repeat the observations taken in (1) at a time when the astronomical conditions are different. The greater this difference can be the better, in theory at any rate. If this principle is applied blindly, however, the streams may possibly be so weak as to be virtually unmeasurable.

(3) If he is able to exercise any choice in the matter, the surveyor should not observe the tidal flow unless the weather conditions are good, e.g. suitable for boat sounding. If the weather deteriorates during the course of a series of observations, common sense must be applied in deciding when to break them off; it will usually be pointless to continue in winds above force 5. However, it must not be forgotten that on occasions even the most unreliable observations* may be better than no observations at all.

b. Equipment

(i) The pole logship. The most important observation from the navigational point of view, and the one that should always be given priority in the absence of special instructions, is that which measures the average direction and rate of the tidal flow between the surface and a particular depth. The depth should, if possible, equal the average draught of vessels likely to pass the point of observation.

The pole logship, which is used to obtain this type of observation, consists of a spar or tube, of uniform thickness throughout its entire length, and weighted so that it floats vertically with its upper end just showing above water. The weights should either form part of the spar itself, or be encased within it. The pole is conveniently made up of sections which may be fitted together to obtain the required length. At the present time (1967) the longest pole in use has a length of 30 feet. With the advent of vessels drawing much more than this, longer poles may well be used in the future; these will be more difficult to handle than the present 30 feet pole, but will not differ from it in the way they are used.

If the movement of a pole logship is to be followed visually, it should be fitted with a small topmark and a light, to enable it to be seen after dark. Catseyes, which will show up in the beam of a lamp, may be used instead of the light if desired.

(ii) Radar transponders in pole logships. A pole logship consisting of a tube made of plastic or other suitable material, about six inches in diameter, may be fitted with a radar transponder, which will enable it to be tracked by the ship's radar. The method of use of such an instrument is described in Section **17c(ii)** below.

(iii) Loglines. used for tidal stream observations are usually made of codline, or something similar. They should be at least 300 feet long, with small corks attached at intervals of 10 or 15 feet so that they will float. They should be marked every 10 feet, starting with a zero mark at a point about 50 feet from the logship end; the markings may well be similar to those used on a leadline. Care is necessary to ensure that the markings are, in fact, 10 feet apart when the logline is actually in use, and wet.

(iv) Tidal flow meters. Several types of tidal flow meter are in use at the present time. All are relatively simple to use, and are accompanied with the maker's detailed instructions on their use and maintenance. Some are more reliable than others.

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* This unreliability must of course never be due to causes under the surveyor's control.

Tidal flow meters can only measure the direction and rate of the stream at the depth of their sensitive elements. They cannot measure the average rate and direction between the surface and a certain depth, which is what most mariners want to know. For this reason these meters in their present form are not likely to replace the pole logships referred to above. They are in fact suited more to oceanographic investigations than to the observation of tidal streams for navigational purposes.

(v) Logships for special purposes. On occasions the surveyor may be required to observe the tidal flow for special purposes. For instance, he may be asked to determine how the topmost layers of water (perhaps to a depth of a foot or so) move about under the influence of the tides and wind. In such circumstances suitable logships can always be made on board. The golden rule to remember is that they must have as great a vertical cross sectional area as possible in the water layer where measurements are to be made, and have little or no resistance to wind or water outside this layer. They must, of course, have a constant width throughout the water layer in which the observations are being taken.

c. Observing tidal flow with a free floating logship

Except in special circumstances tidal flow observations should be made about once an hour. The exact time of observation is not critical, though it may well sometimes be convenient to observe at whole hours either before or after high water at the nearest standard port. The central time of a particular observation should be noted, and used in all subsequent calculations.

There are two main methods of observing tidal flow. In the first, which should always be used if possible, a free floating logship is allowed to drift with the tide, and fixed at intervals either from the shore or an accompanying craft. In the second (see Section **17d** below) the logship is allowed to drift on a line astern of an anchored vessel, and its movement relative to the sea-bed is calculated from the observations; this method requires less expenditure of time and manpower, but it generally has inherent defects which are difficult to eradicate.

(i) Visual observation of a free floating logship. The position of observation should either be easily recoverable from transits, or marked by a small buoy.

The procedure is as follows:

(*a*) The logship is carried in a boat, and for each observation it is released close upstream of the buoy. As soon as it is drifting freely its position is fixed; the boat then backs carefully away, and drifts with it. Great care must be taken to ensure that the logship is not disturbed by the wash from the boat's propeller.

(*b*) After a suitable interval the logship is approached once more, very carefully, and its position fixed again.

(*c*) At least three fixes should be taken before the logship is recovered.

(*d*) Times may be measured by stopwatch; they must be recorded to the nearest second.

(*e*) Each run should be plotted on a large scale as soon as it has been completed. The three (or more) fixes should lie in a straight line. If they do not then either errors of fixing are present, or the tidal flow has altered during the run; common sense must be used in deciding which is more likely.

(*f*) The direction of the tidal flow may be taken directly off the plot. Its rate may be calculated on the assumption that a rate of one knot equals 100 feet/minute.

(*g*) Any sensitive method of fixing, either visual or electronic, may be used. In some cases it may be more convenient to fix the logship by means of theodolite or sextant observations from the shore. At night it may be necessary to illuminate the fixing objects.

(*h*) The longer each individual run can be, the better, so long as there is no chance of the tidal flow itself altering appreciably during the run.

The result of the observations will be a series of observed directions and rates of the tidal flow, obtained at approximately hourly intervals.

(ii) Radar observations to a free floating logship. It may happen that tidal flow observations are required in a position where it is impossible either to obtain visual fixes from the shore, or to use a sensitive electronic fixing aid.

If the logship can be fitted with a radar transponder (or perhaps even a good radar reflector) then the following method may be used. The transponder or reflector must, of course, be fitted so that it does not cause the logship to sail before the wind.

(*a*) The ship is anchored in the observing position. Anything that can be done to reduce her movement about her anchor will be an advantage.

(*b*) For each observation the logship is released and allowed to drift well clear on the tide. It is then fixed by gyro or radar bearing, and radar distance every half minute for at least five, and perhaps even 10 minutes, depending on the strength of the tidal flow. The stronger the flow the shorter the period need be. Fixes are plotted on a mooring board, or something similar, using as large a scale as possible.

(*c*) If the ship remains stationary during the period of observation (she is not very likely to do so) the fixes at half minute intervals will lie in a straight line and will be evenly spaced. If she is yawing about her anchor her motion will be superimposed (in the opposite sense) upon that of the logship, but the mean motion of the latter over a period of five or ten minutes will be relatively free from error due to this cause. Whatever happens the surveyor will be able to see it on his plot, and use his judgement and experience to obtain the motion of the logship relative to the sea-bed.

(*d*) After each observation the logship is recovered by boat.

Provided there is plenty of sea room, and the logship does not get too far away, it may be allowed to drift freely for some hours, being fixed relative to the ship by radar every five minutes or so. Rates and directions of the tidal flow may then be taken off a large scale plot whenever they are required.

d. Tidal flow observations using a logline

The opening remarks of Section **c** above apply equally well if tidal flow observations are being made with a logship and logline. In this method the logship is allowed to drift on the end of a logline for a certain time; its movement relative to the sea-bed is calculated by observing compass bearings and logline distances into it, and allowing for the movement of the observer, who will generally be on the stern of an anchored vessel.

For the results to be reliable the observer must be able to measure his own movement during the observations with certainty. It is not easy to measure the movement of the stern of a vessel as she yaws about her anchor, unless an accurate electronic fixing aid is available.* For this reason, and also because a logship drifting away from a ship is bound to be influenced to some extent by the eddies flowing round her hull, it will generally be better to use one of the methods described in **c** above in preference to that set out below.

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* Hi-fix and Hydrodist are sufficiently precise, but Decca is not.

(i) Observing procedure. Assuming that the observer can measure his own movement accurately, the observing procedure is as follows:

(*a*) Reeve the logline through a fairlead aft; secure the logship to the logline, and lower it into the water.

(*b*) Allow the logship to drift away freely on the tide, keeping the logline just slack. As the zero mark of the logline (about 50 feet from the logship) passes through the fairlead, start the stopwatch and observe the bearing of the logship by compass. A gyro compass should be used for preference. Then make certain that the logline does not affect the motion of the logship, by keeping it quite slack.

(*c*) One or two minutes later, depending on the rate of flow, observe the bearing of the logship once more, take in the slack of the logline, and note the amount which has run out. The more logline that runs out during an observation, the better it will be, however, if the tide is very slack there will be no point in going on for much more than two minutes.

(*d*) Repeat these observations twice, to obtain a set of three.

A typical set of observations is shown in the table below:

	RUN 1	RUN 2	RUN 3
Duration of run	2 mins	2 mins	2 mins
Bg. at start (50 ft.)	200°	180°	265°
Bg. at finish	198½°	187°	154°
Logline out at finish	108 ft.	180 ft.	185 ft.
Distance of logship at finish	158 ft.	230 ft.	235 ft.

These observations have been plotted in Figs. 2–33(*a*), (*b*) and (*c*), and combined in Fig. 2–33(*d*) to give a tidal flow of 0·83 knots towards 157½°. For convenience the tidal flow distances in Fig. 2–33(*d*) have been plotted as half the relevant observed distances; they therefore correspond to run durations of one minute. Note that the three runs are not equal, either in direction or rate; judgement must be used when deciding how great the discrepancies between them may be before a set of observations must be rejected. These shown here are typical of the results that should be obtained, provided the observer can measure his own movement accurately.

In practice all three runs can be plotted and combined on the same mooring board or sheet of squared paper.

(ii) Measuring the observer's own movement. It is comparatively simple to make the observations described in (i) above. If visual fixing is not possible it will not be nearly so easy to measure the movement of the stern of a vessel which is yawing about her anchor, under the influence of tide and wind.

If Hi-fix or Hydrodist are available, an electronic fix, combined with a reading of the ship's head and the fixed distance between the aerial and the observing position aft, will enable the observer to obtain his position whenever he wishes. Uncorrected Hi-fix or Hydrodist readings may always be used, since absolute positions are not required.

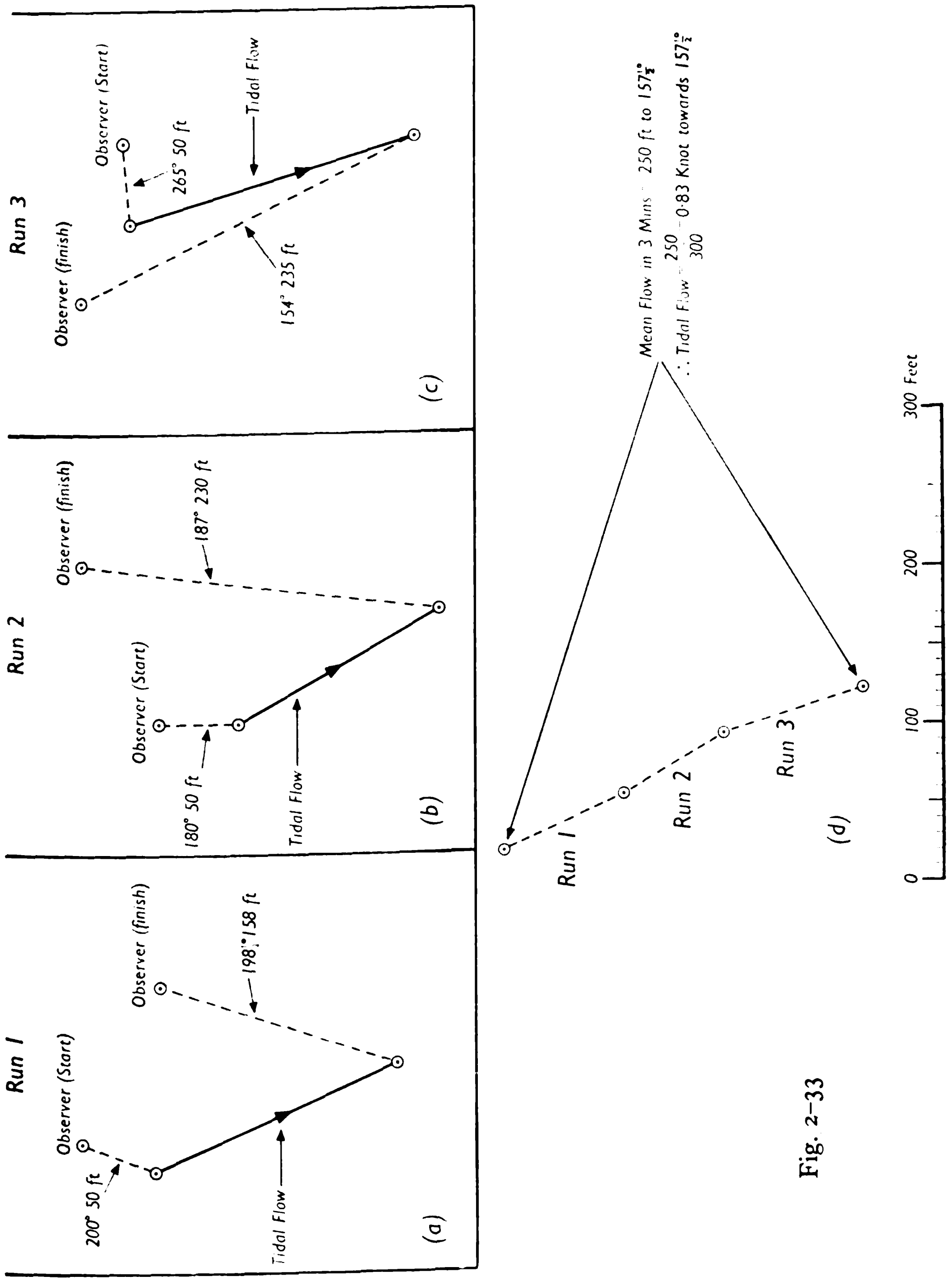

Run 1
Observer (Start)
200° 50 ft
Observer (finish)
198½° 158 ft
Tidal Flow
(a)
Run 2
Observer (finish)
187° 230 ft
Observer (Start)
180° 50 ft
Tidal Flow
(b)
Run 3
Observer (Start)
265° 50 ft
Tidal Flow
Observer (finish)
154° 235 ft
(c)
Mean Flow in 3 Mins = 250 ft to 157½°
∴ Tidal Flow = 250/300 = 0·83 Knot towards 157½°
Run 1
Run 2
Run 3
(d)
300 Feet
200
100
0

Fig. 2–33

Two radar ranges to transponders placed ashore should also give a good fix in these circumstances. One radar range, combined with a gyro or radar bearing, may be good enough if the transponder is not too far away; the determining factor will be the likely error of the gyro or radar bearing.

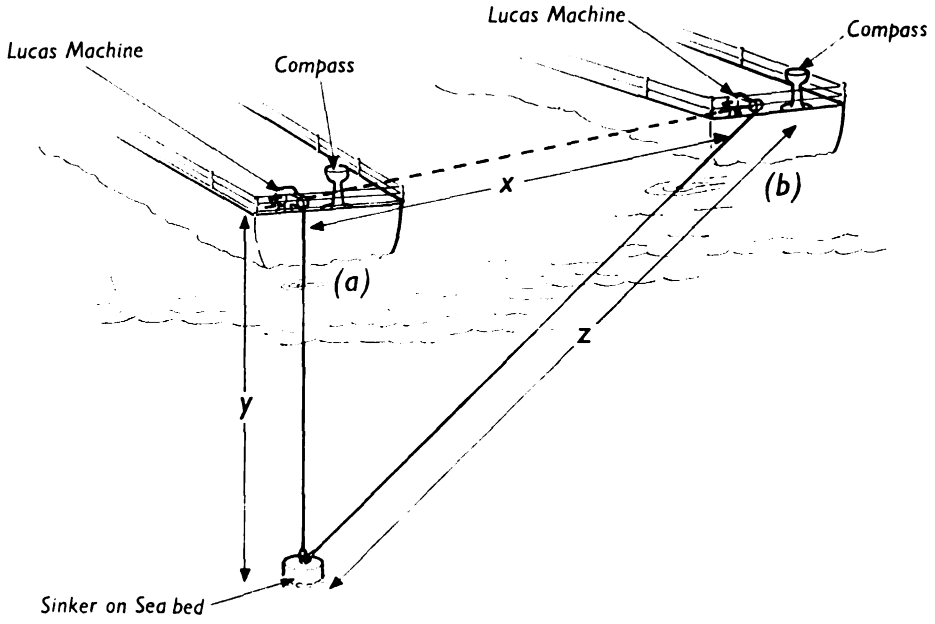


Fig. 2–34

In Fig. 2–34 the surveyor, who has no visual or electronic devices to help him, is measuring the movement of the stern of his vessel relative to the sea-bed. He has rigged up a Lucas sounding machine on the ship's transom, close to the compass which will be used to observe tidal streams. The sinker should weigh about half a hundredweight; the heavier it can be the better, provided it can be handled fairly easily; it may be necessary to replace the normal brass sheer pins in the Lucas machine with steel ones.

At (*a*) the zero mark of the logline (referred to in (i) above) has just passed through the fairlead. The sinker is lowered on to the bottom, and the distance y, which is the height of the Lucas dial above the sea-bed, is read off and noted. As the logship drifts away on the tide the ship's stern will be moving, and it will have reached (*b*) at the end of the observation. At this moment the distance z is read off the Lucas dial, and the direction in which the Lucas wire is leading is observed with the compass.

If the horizontal movement of the stern in the observed direction is x, then

$$x^2 = z^2 - y^2.$$

The equation can be solved mathematically, or x can be found directly by graphical means.

Errors in the horizontal distance x will depend on the ratio y/z. The greater z can be relative to y the smaller will these errors be. Suppose that $y = 100$; then for the given values of z the table below shows the factors by which errors of observation will be magnified when calculating x.

TABLE OF ERRORS WHEN MEASURING MOVEMENT OF SHIP'S STERN BY LUCAS MACHINE AND COMPASS

(See Fig. 2–34)

$y = 100$

z	ERRORS IN x ARE MAGNIFIED BY	APPROXIMATE VALUE OF x
103	4	26
106	3	35
115	2	58
134	1½	90

Example:

Suppose that $y = 64$ feet, $z = 74$ feet and that the errors of observation are ± 2 feet in each measurement, so that they might combine to give ± 4 feet in the worst case.

Then $z/y = 74/64 =$ just over 115 per cent.

Therefore the errors in x will be ± 8 feet at the most.

Provided the Lucas machine is set up and used carefully, and great care is taken in observing the bearing of the lead of the wire at the second observation, this method should produce reasonable results.

If possible observations should be carried out when the ship is surging ahead on her cable; if this is not done there will be a risk that the Lucas wire will grow forward under the stern, where it will be impossible to observe and in grave danger of becoming fouled in the rudder and propellers.

It is most important to note that in no circumstances is it permissible to assume that the ship will pivot about her anchor, or that the movement of her stern may be deduced solely by observing changes in the direction of the ship's head. The actual movement of the stern very often takes the form of a figure of eight, and very large changes can take place without any appreciable alteration in the direction of the ship's head.

18. Analysis of Tidal Streams

Two methods of analysis are available to the surveyor at the present time (1967). In the first the tidal flow is analysed harmonically, in a way similar to that used for the vertical movement of the tides. In the second semi-graphic methods are employed to obtain an empiric relationship between the tidal stream at a place and the tide at a suitable standard port.

When only 25 or 50 hourly observations have been obtained, the first method must assume that the sun and moon proceed round the earth in circular orbits, at a constant speed; the analogy in tidal work would be to assume that the only relevant tidal constituents were M_2, S_2, K_1 and O_1. The second (semi-graphic) method cannot handle diurnal inequalities in the tidal stream, and assumes that the tidal streams are completely semi-diurnal. These assumptions are far from being satisfactory, but owing to the paucity of the observations which are generally available for analysis they must be made in order to obtain any results at all.

The surveyor in the field need not worry himself unduly over this state of affairs. His main task will always be to obtain reliable observations. If he carries out an analysis and is not very impressed with its results (as he may well be) he should forward his observations to the relevant tidal department with his analysis and comments, and leave it at that.

The harmonic and semi-graphic methods are described separately below.

a. Harmonic analysis of tidal streams

The end product of a set of tidal stream observations will be a series of rates and directions of the tidal flow at approximately hourly intervals.

Before these can be analysed harmonically they must be split up into their component rates in two directions at right angles. For instance, a flow of one knot in a direction 030° could be split up into rates of 0·87 knots North and 0·5 knots East. Any two directions may be chosen for the axes, so long as they are at right angles; but it will make subsequent calculations easier if one is chosen to coincide with the direction of maximum flow of the tide, and the other at right angles to this direction. If the tide merely flows back and forth (and is 'rectilinear') then one analysis carried out in this direction will suffice; if it has a rotary motion two analyses will be necessary, one for the direction of maximum flow and one at right angles to this direction. If the streams are very nearly, but not quite rectilinear, then sometimes only one analysis is carried out, and the stream components at right angles to the direction of maximum flow are neglected.

In every case the method of analysis is similar to that used for short period tidal observations; it is described in *Admiralty Tidal Handbook No. 3, Harmonic Analysis for Short Period Observations.*

Where a rectilinear stream has a large diurnal inequality this method will provide tidal stream constants which may then be used for prediction using a machine or *Form HD* 289. No reliable means have yet been discovered of producing predictions when a stream having a large diurnal inequality is also rotary, making it necessary to carry out both the analyses referred to above.

The surveyor is not very likely to be required to use this method, except in special circumstances. It is sometimes useful, however, in providing him with an idea of the magnitude of the diurnal tidal stream constituents K_1 and O_1, relative to the semi-diurnal constituents M_2 and S_2. It has been found that the best results are obtained from the semigraphic method, described in **b** below, when the tidal streams at a place are related to a tide which has similar diurnal and semi-diurnal characteristics; this may well, of course, occur at a standard port some distance away from the scene of tidal stream observations.

b. Semi-graphic analysis of tidal streams

The surveyor who has taken tidal stream observations will have a series of hourly measurements of the direction and rate of the tidal flow, extending over a period of 25 or 50 hours. If the longer period has been used, it should be split up into two periods of 25 hours, and each of these should be analysed separately. Most tidal departments issue instructions as to the standard port to which the streams in a particular area should be referred. In the absence of such instructions the surveyor may always use the standard port nearest to his survey area.

Tidal streams may flow more or less back and forth, and be rectilinear; or they may be rotary. They may or may not have appreciable diurnal inequalities. The observations may perhaps be affected by weather conditions which change whilst they are being taken. In every case the surveyor must isolate and remove the residual motion (sometimes loosely referred to as current) from his observations. He will, of course, also wish to remove all the effects of weather, and he must of necessity remove any diurnal inequalities that may be present; these two operations require judgement, and no two people are likely to obtain exactly the same results.

Although the semi-graphic method of analysis is far from being perfect, it does enable the surveyor to do all of these things; more important perhaps, it clearly shows both him and anyone else what he is doing, and gives him a very reasonable idea of what errors are likely to be present.

The method of analysis may best be explained by working through two examples. The first is of an approximately rectilinear tidal stream, without complications. The second is of a rotary stream where complications are present. Both these examples are taken from actual observations.

(i) Analysis of a rectilinear stream with no complications. The following observations were obtained off Milford Haven on 3rd and 4th October 1952:

TIME	TIDAL FLOW		WIND		TIME	TIDAL FLOW		WIND	
	DIRN.	RATE	DIRN.	FORCE		DIRN.	RATE	DIRN.	FORCE
		knots					*knots*		
2000/3	275°	1·1	Calm		1000/4	246°	2·2	Calm	
2100	259°	1·9	Calm		1100	271°	2·2	Calm	
2200	246°	2·0	Calm		1200	252°	1·7	020°	1
2300	251°	2·1	Calm		1300	239°	0·7	050°	1
2359	258°	1·3	090°	1	1400	Slack		060°	1
0100/4	212°	0·3	150°	1	1500	078°	1·0	050°	1
0200	085°	0·2	140°	1	1600	089°	2·0	050°	1
0300	096°	1·4	140°	2	1700	092°	2·2	040°	1
0400	089°	2·1	140°	2	1800	089°	2·2	030°	1
0500	078°	2·1	210°	2	1900	094°	1·6	040°	2
0600	090°	2·1	230°	2	2000	153°	0·5	050°	2
0700	095°	1·2	230°	2	2100	256°	1·7	050°	2
0800	249°	1·3	220°	1					
0900	261°	1·6	Calm						

Times of high water at Milford Haven, the standard port, were:

1909/3
0727/4
1948/4.

By the time he has set the above table out in this form, the surveyor will already know two things:

(1) That the tidal stream is flowing backwards and forwards in an approximately east–west direction.

(2) That the weather should have no significant effect on the observations.

To carry out the analysis, proceed as follows:

(*a*) Plot the observed rates of flow and directions of flow on graph paper. The plots from the table above are shown in Fig. 2–35. Join the plotted points with a smooth curve, making certain that it does pass through each point. Do not, at this stage, reject any of the observations, unless there is evidence for doing so exterior to the plot.

In this case the observed rates seem reasonable. The surveyor might be tempted to draw a mean curve for the observed directions between 0800/4 and 1200/4. It will be better not to do this, however, since there is no real reason why the direction of flow should not have changed as indicated.

The object of making these plots is to interpolate rates and directions with respect

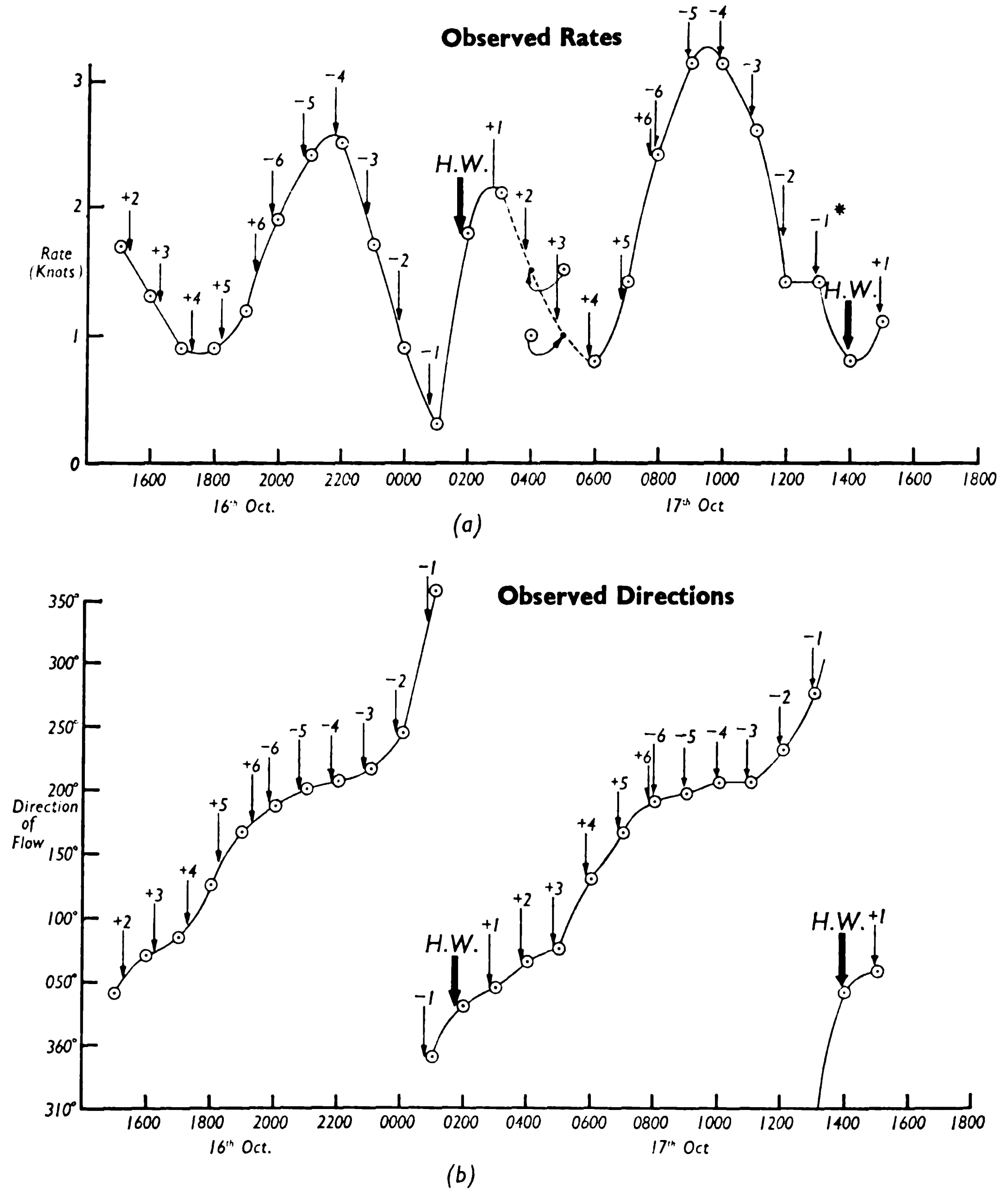


Fig. 2-35

to the various high waters, without introducing any arbitrary smoothing or adjustments.

So:

(*b*) Draw in the various times of high water, 1909/3, 0727/4 and 1948/4 in this case, and then the lines indicating whole hours before (—) and after (+) the high waters. All these times are indicated by labelled arrows in the figure.

(*c*) Take off from the two graphs the rates and directions corresponding to the various hours before and after high water. Since the analysis covers a period of 24 'tidal' hours, there will be two complete cycles, from H.W. to H.W. Values in this case, taken from Fig. 2–35, are tabulated in columns 1 to 4 of the table below. Note that the cycles start one hour after high water.

	1	2	3	4	5	6
	RATES		DIRECTIONS		MEANS	
	1ST CYCLE	2ND CYCLE	1ST CYCLE	2ND CYCLE	RATE	DIRN.
	knots	*knots*			*knots*	
H.W.	0·7*	1·1	145°*	200°	0·9	172°
1 hour after H.W.	1·1	1·4	273°	257°	1·2	265°
2 hours after H.W.	1·9	1·9	255°	255°	1·9	255°
3 hours after H.W.	2·0	2·3	246°	260°	2·1	253°
4 hours after H.W.	2·1	2·0	253°	265°	2·0	259°
5 hours after H.W.	1·2	1·2	255°	245°	1·2	250°
6 hours after H.W.	0·3	0·3	190°	210°	0·3	200°
6 hours before H.W.	0·2	0·1	130°	185°	0·1	157°
5 hours before H.W.	0·7	0·8	090°	082°	0·7	086°
4 hours before H.W.	1·8	1·9	093°	088°	1·8	090°
3 hours before H.W.	2·1	2·2	080°	093°	2·1	086°
2 hours before H.W.	2·1	2·2	085°	090°	2·1	087°
1 hour before H.W.	1·8	1·8	092°	093°	1·8	092°

If the tidal stream had been completely semi-diurnal, and if there had been no errors of any sort in the observations, the various values in columns 1 and 2, and columns 3 and 4 would have been identical. The discrepancies here are a measure of the errors which are likely to affect the final result of the analysis. In this case these discrepancies are reasonable; the only one that might possibly cause doubt is that between the two directions at H.W. (145° and 200°); since at this time the stream is changing direction it can be accepted; it would not be acceptable if it occurred at a time when the stream was running in a steady direction.

The two cycles of rate and direction are now meaned to give the values tabulated in columns 5 and 6. This process removes any diurnal component that may be present. It is not a desirable one, but must be carried out sometime if the analysis is to yield useful results.†

The next step is to find out what residual motion may be affecting the observations and to remove it, so that the pure tidal stream is left.

So:

(*d*) Plot the values in columns 5 and 6 of the table as polar co-ordinates, on a mooring board or sheet of graph paper. They are shown on Fig. 2–36, relative to the point of origin.

Find the position of the point *A* by the method set out in (**ii**) below. The vector from the point of origin to *A* represents the residual motion which is affecting all the observations; and the true tidal stream vectors must be measured not from the point of origin, but from *A*.

(*e*) Make a new table, showing the residual motion and the tidal stream information.

---

* This was the penultimate observation, not the first.

† If the discrepancies are large, it may be wise to plot the two cycles separately on Fig. 2–36, and mean them on the diagram. Generally, however, the meaning may be done before the plot is made.

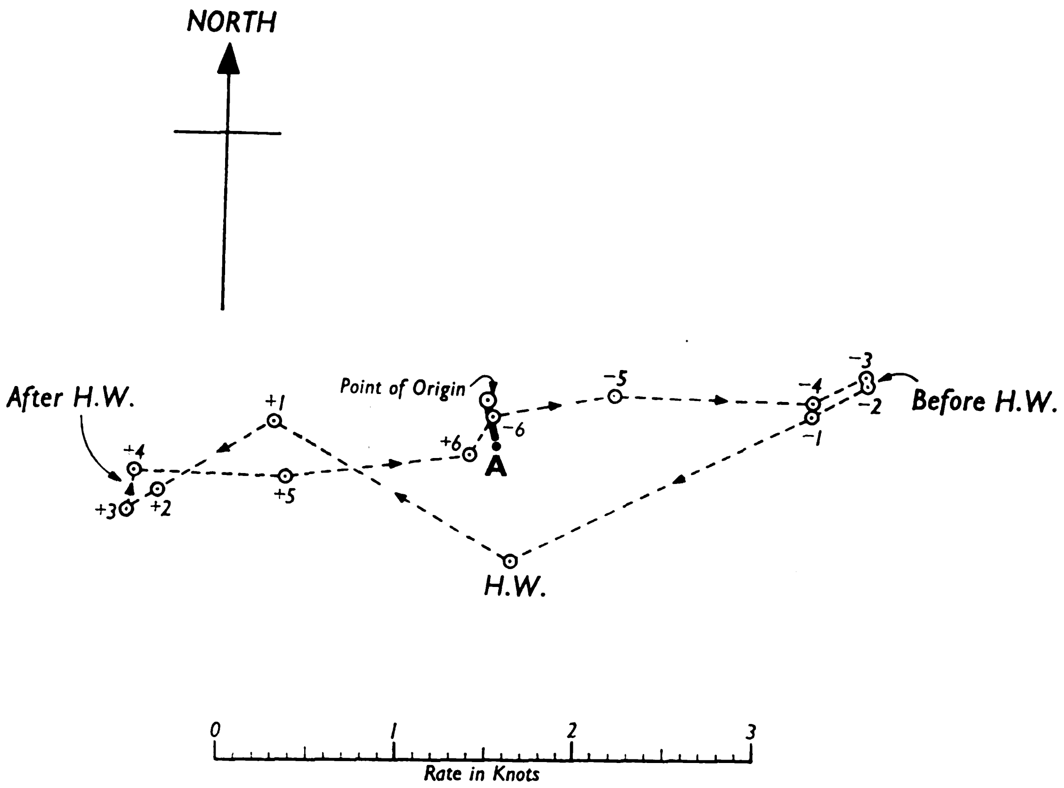


Fig. 2–36

Note that it is now arranged differently, with H.W. placed centrally. This new information is shown in columns 1 and 2 of the table below.

TIDAL STREAMS OFF MILFORD HAVEN 3RD–4TH OCTOBER 1952	1	2	3	4
	DIRNS. OF FLOW	RATES OF FLOW		
		3RD–4TH	SPRING	NEAP
		knots	*knots*	*knots*
6 hours before H.W.	360°	0·2	0·2	0·1
5 hours before H.W.	067°	0·7	0·6	0·3
4 hours before H.W.	002°	1·8	1·5	0·7
3 hours before H.W.	079°	2·1	1·8	0·8
2 hours before H.W.	080°	2·1	1·8	0·8
1 hour before H.W.	084°	1·8	1·5	0·7
H.W. Milford Haven	172°	0·7	0·6	0·3
1 hour after H.W.	276°	1·2	1·0	0·5
2 hours after H.W.	262°	1·9	1·6	0·8
3 hours after H.W.	260°	2·1	1·8	0·8
4 hours after H.W.	266°	2·0	1·7	0·8
5 hours after H.W.	261°	1·2	1·0	0·5
6 hours after H.W.	253°	0·1	0·1	0·0

Residual Motion
0·25 knot towards 172°
At Milford Haven
Mean Range for day (from *Tide Tables*) } 23·7 ft.
Mean Spring Range 20·4 ft.
Mean Neap Range 9·5 ft.
(Both these come from *Table V* of the *Tide Tables*)

$$\text{Spring factor} = \frac{20{\cdot}4}{23{\cdot}7} = 0{\cdot}86$$

$$\text{Neap factor} = \frac{9{\cdot}5}{23{\cdot}7} = 0{\cdot}40$$

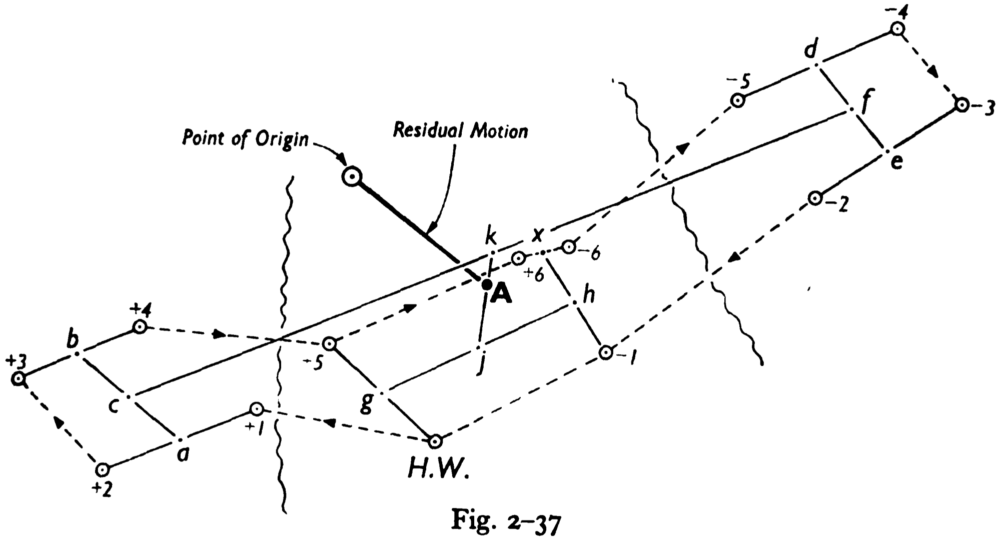


Fig. 2–37

It is assumed that the directions of flow will remain constant under all astronomical conditions, relative to the time of high water.* In the same way the rates are assumed to be directly proportional to the range of the tide at the standard port concerned.* In this case therefore spring and neap ranges are found from the tide tables for Milford Haven, and divided by the mean range for the period of observation to obtain spring and neap factors. The relevant figures are noted beside the table. Note that both factors are less than one; this is a result of observing when the streams were flowing most strongly. It reduces errors of all sorts. The spring and neap rates are shown in columns 3 and 4 of the table.

(*f*) The following records should be forwarded to the relevant tidal department when the analysis has been made:

(1) A note of the original observations, including wind and weather.
(2) The curves in Fig. 2–35, accompanied by the table in (*c*) above.
(3) The plot in Fig. 2–36, accompanied by the table in (*e*) above.
(4) The surveyor's remarks on the observations and analysis. If there is an apparent diurnal inequality, or if the residual motion may possibly have been changing during the period of observation, it is particularly important that the surveyor should give his opinion as to whether these phenomena could have been caused by changing weather conditions.

(ii) Residual motion; finding the position of the point A. Fig. 2–37 shows a set of tidal stream observations which have been plotted in accordance with the instructions set out above. It is required to find the position of the point *A*. The procedure is as follows:

(*a*) Select the point *x*, so that it bisects the line joining observations +6 and −6.

(*b*) Divide the figure into three parts, each containing four hourly points, using the point *x* as a substitute for both +6 and −6. See the wavy lines in the diagram.

(*c*) Insert point *a* as the mid point of the straight line +1, +2. Insert *b* as the mid point of the straight line +3, +4. Bisect *ab* to obtain the point *c*.

---

* These assumptions are clearly not true, since the tidal streams do not behave in this conveniently simple fashion. However, this is the best that can be done at present.

(*d*) Insert *d* as the mid point of −4, −5; and *e* as the mid point of −3, −2. Bisect *de* to obtain *f*.

(*e*) Repeat the process in the central section to obtain *g* from H.W., +5, and *h* from *x* and −1. Bisect *gh* to obtain *j*.

(*f*) Bisect *cf* to obtain *k*.

(*g*) Then the point *A* lies on the line *jk*, two-thirds of the way from *j* to *k*, and the residual motion is represented by the vector from the point of origin to *A*.

NOTE:

1. It does not matter how the original figure is divided into three parts, so long as each part contains four plotted points.
2. Neither does it matter how the plotted points are combined to produce the points *a*, *b* and *c*, etc. In the left hand section in this case the grouping could equally well have been +2, +3, and +1, +4.
3. The point *A* is the centre of gravity of masses one unit at the 11 points −5 to +5, and masses half a unit at the points +6 and −6. It is not the centre of gravity of the area enclosed by the plotted points, and in some cases it may well lie outside this area.

(iii) Analysis of a rotary stream, with complications. The observations described here were obtained off Longsand Head, in the Thames Estuary, on 16th and 17th October 1951. They illustrate a typical rotary stream, and the difficulties which are likely to lie in wait for the unwary surveyor.

The general method of analysis is the same as that described in (i) above; some modifications to it are made to deal with the rotary stream and the various difficulties that arise.

The following observations were obtained:

TIME	TIDAL FLOW		WIND		TIME	TIDAL FLOW		WIND	
	DIRN.	RATE	DIRN.	FORCE		DIRN.	RATE	DIRN.	FORCE
		knots					*knots*		
1500/16	041°	1·7	120°	1	0400/17	066°	1·0	280°	2
1600	070°	1·3	120°	1	0500	076°	1·5	280°	3
1700	084°	0·9	040°	1	0600	131°	0·8	280°	1
1800	125°	0·9	040°	1	0700	168°	1·4	280°	1
1900	167°	1·2	050°	1	0800	191°	2·4	290°	1
2000	188°	1·9	Calm		0900	198°	3·1	350°	2–3
2100	200°	2·4	Calm		1000	206°	3·1	015°	4
2200	204°	2·5	Calm		1100	205°	2·6	010°	5
2300	212°	1·7	Calm		1200	230°	1·4	010°	5
2359	246°	0·9	360°	1–2	1300	273°	1·4	010°	7
0100/17	354°	0·3	330°	2–3	1400	041°	0·8	010°	7
0200	030°	1·8	300°	4	1500	056°	1·1	360°	6
0300	045°	2·1	300°	4					

Times of high water at Sheerness, the standard port, were:

1315/16
0150/17
1355/17.

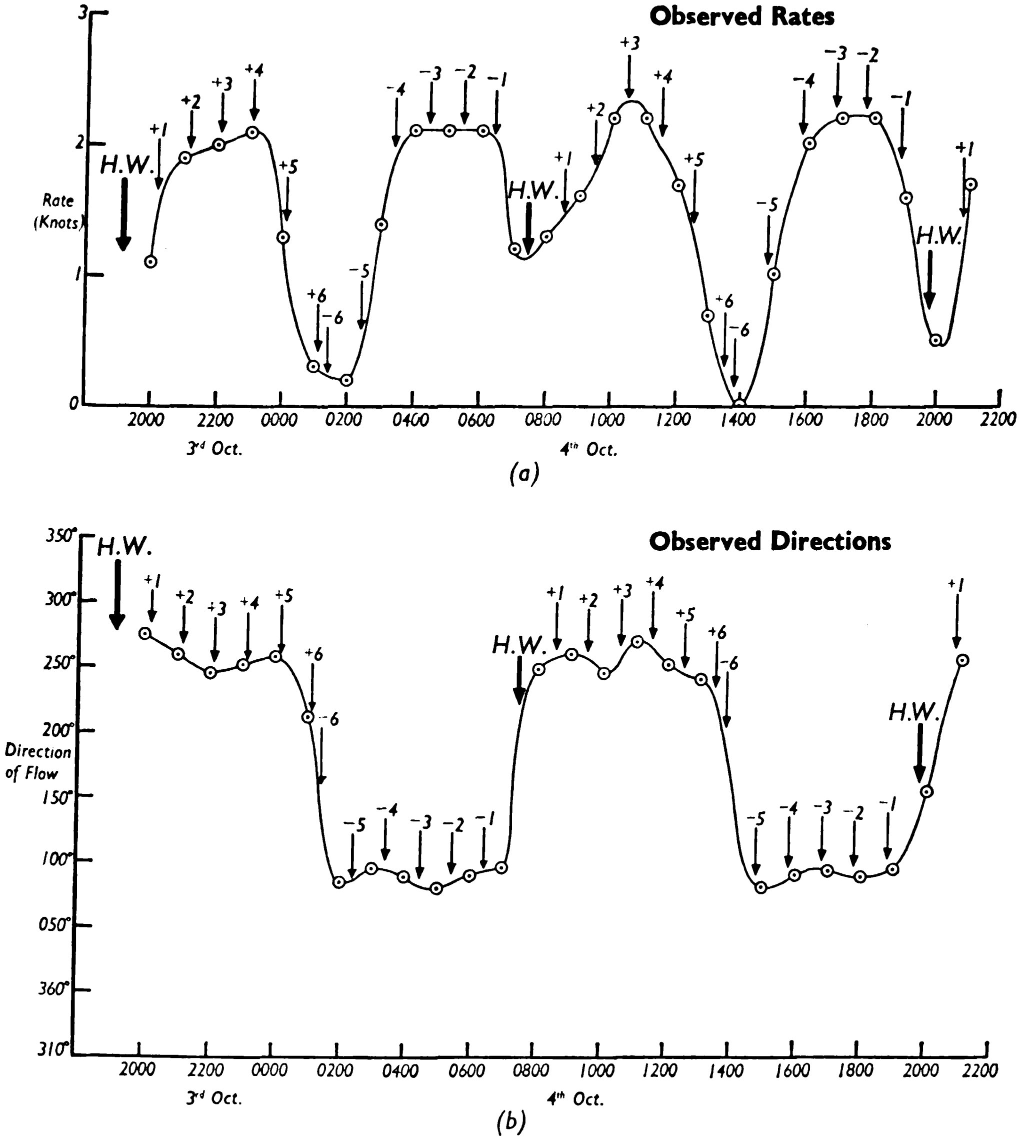
Note that the observations cover a period of 24 hours only, and not 25, as should have been the case.

The surveyor who took the observations in this table must have watched the wind increase to gale force from the north towards the end of the period. He should, in fact, have rejected them as being unreliable, and not analysed them at all. The effect of his error of judgement in accepting them will be seen below.

The analyst must proceed as follows:

(*a*) Plot the observed rates of flow and directions of flow on graph paper. The plots are shown in Fig. 2–38.

It is obvious at once that there is no overlap between the beginning and end of the observations, relative to H.W., as there was in Fig. 2–35. The observations should have been started one hour earlier, at 1400/16, or continued until one hour later.



(*a*)

(*b*)

Fig. 2–38

But for this, the observed directions look reasonable. Note that there is an appreciable amount of 'diurnal inequality of time' present, the two cycles from H.W. to H.W. differing by 30 minutes. (See the times of H.W. Sheerness above.)

Clearly there is something very suspicious about the observed rates at 0400/17 and 0500/17. Either the stream is behaving in a very unlikely manner, or these two observations have been transposed by accident in the field record. It is reasonable to infer the latter alternative in this case. and to accept the pecked line between 0300/17 and 0600/17 in Fig. 2–38(*a*). However, this assumption, reasonable though it may be, must reduce the reliability of the analysis.

These points are made here in order to emphasise how easy it is to vitiate a whole series of observations by a lack of care and attention to detail.

Compare Fig. 2–38(*b*) with Fig. 2–35(*b*), and note the typical characteristics of rotary and rectilinear streams.

(*b*) Draw in the various times of high water, 0150/17 and 1355/17 in this case, and then the lines indicating various times after and before high water. Some of these lines in the figure are based on the high water at 1315/16, which cannot be plotted. All these times are indicated by labelled arrows.

(*c*) Take off from the two graphs the rates and directions corresponding to the various times before and after high water.

There will be two cycles, which are shown in the table below.

	RATES		DIRECTIONS	
	1ST CYCLE	2ND CYCLE	1ST CYCLE	2ND CYCLE
	knots	*knots*		
2 hours after H.W.	1·6	1·6	052°	063°
3 hours after H.W.	1·2	1·1	074°	073°
4 hours after H.W.	0·9	0·8	092°	119°
5 hours after H.W.	0·9	1·2	140°	164°
6 hours after H.W.	1·4	2·3	173°	190°
6 hours before H.W.	1·9	2·4	187°	192°
5 hours before H.W.	2·3	3·1	200°	198°
4 hours before H.W.	2·5	3·1	203°	204°
3 hours before H.W.	1·9	2·6	210°	204°
2 hours before H.W.	1·0	1·4	240°	230°
1 hour before H.W.	0·4	1·4*	325°	273°
H.W.	1·5	0·8	027°	040°
1 hour after H.W.	2·2	1·1	043°	054°

Note that the differences between the first and second cycles, particularly for the rates, are much larger here than they were for the rectilinear tidal stream analysed in (i) above. This indicates that errors are present; and so the two cycles are plotted separately as polar co-ordinates on Fig. 2–39.

This figure indicates two things immediately to the surveyor:

(1) The rate of 1·4 knots at one hour before H.W. in the second cycle (marked with an asterisk on Figs. 2–38 and 2–39, and in the table above) seems to be spurious. A rate of 0·4 or 0·5 at this time seems much more probable. All the analyst can do is to use his judgement, and note that the reliability of the analysis is reduced even further by these doubts. Note that until this stage this reading did not show up as being definitely suspicious.

(2) The last half of the second cycle looks as though it has been affected by the

increasingly strong wind from the north. All the points after 0900/17 (five hours before H.W.) are displaced very much to the south compared with their counterparts in the first cycle. This might or might not be caused by a temporary 'current' set up by the wind.

In normal circumstances no surveyor should proceed beyond this point in the analysis.* The only safe thing to do is to observe again when the weather conditions are suitable.

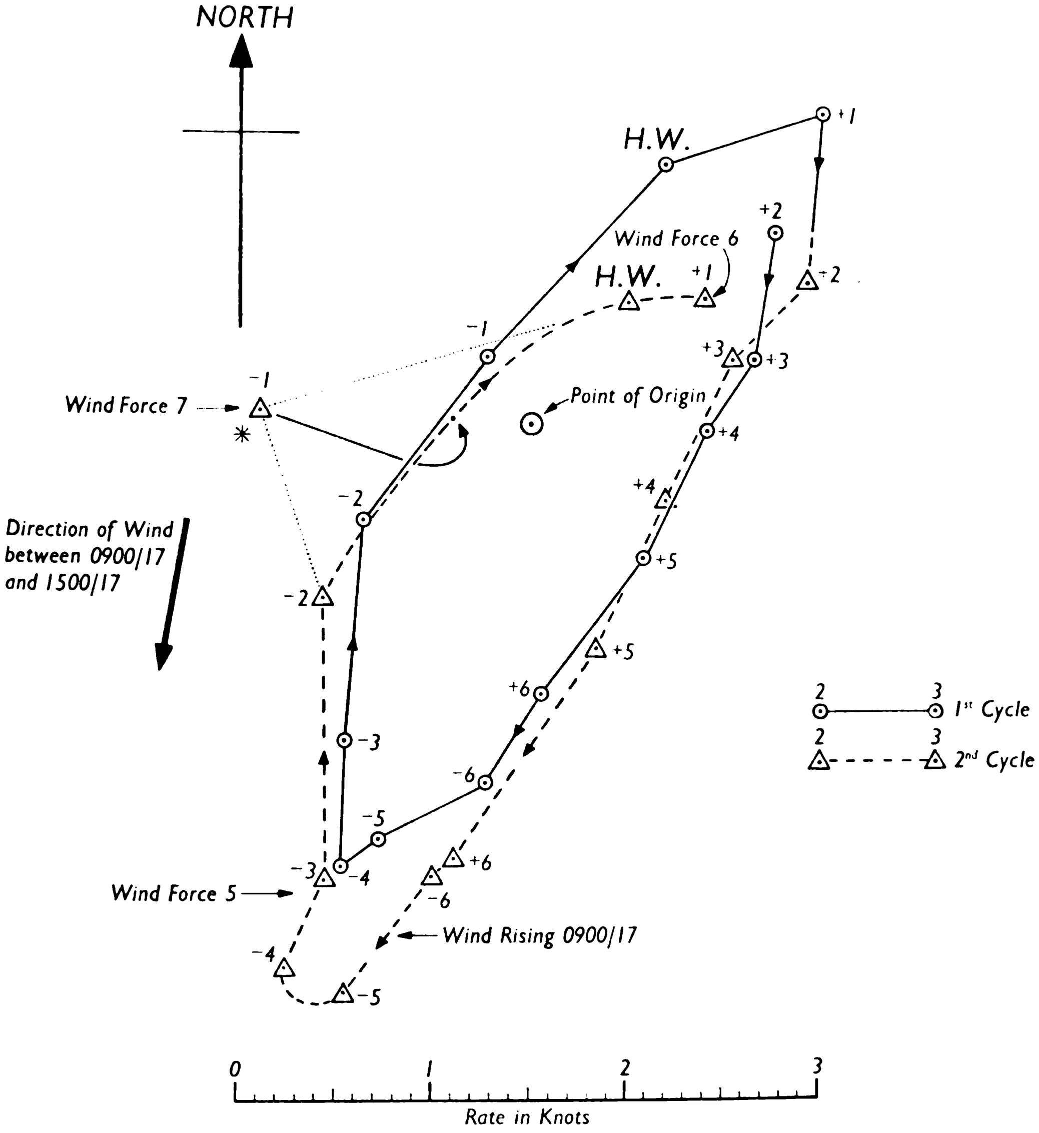


Fig. 2–39

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* He should not in fact have tried to analyse such unreliable observations at all, having seen what the weather was like.

Suppose, however, that these are the only observations available, and that it is vital to get a result of some sort. The surveyor should proceed as follows:

(*d*) The two cycles in Fig. 2–39 must be meaned, and judgement must be applied in doing this. The author has rejected completely the last eight observations in the second cycle, and chosen the most likely mean in the other cases. No two surveyors are likely to agree when doing this. The meaned plot is shown in Fig. 2–40.

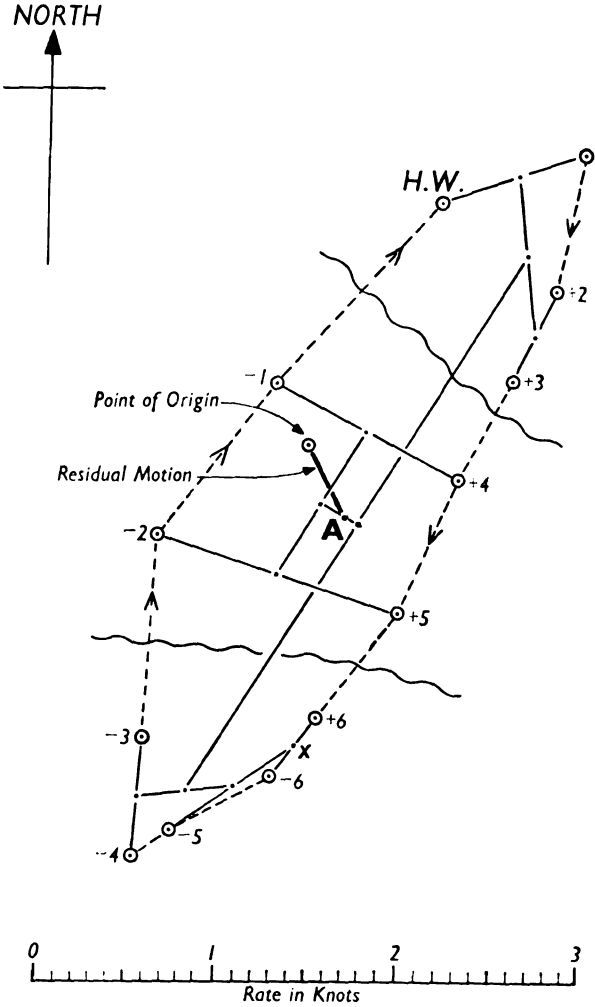

Fig. 2–40

The next step is to find the residual motion. So:

(*e*) Find the position of the point *A* by the method set out in (ii) above. In the figure the point *x* and the various construction lines and points have been drawn in. The vector from the point of origin to *A* represents the residual motion, and the tidal stream vectors must be measured from *A*.

(*f*) Make a new table, showing the residual motion, the tidal stream on the day in question, and the spring and neap rates. The process is the same as that described in step (*a*) of (i) above. The results are tabulated in the table below.

TIDAL STREAMS OFF LONGSAND HEAD 16TH–17TH OCTOBER 1951	DIRNS. OF FLOW	RATES OF FLOW		
		16TH–17TH	SPRING	NEAP
		knots	*knots*	*knots*
6 hours before H.W.	195°	1·5	1·5	0·9
5 hours before H.W.	208°	2·0	2·0	1·3
4 hours before H.W.	211°	2·2	2·2	1·4
3 hours before H.W.	222°	1·6	1·6	1·0
2 hours before H.W.	265°	1·0	1·0	0·6
1 hour before H.W.	332°	0·8	0·8	0·5
H.W. Sheerness	017°	1·8	1·8	1·1
1 hour after H.W.	033°	2·4	2·3	1·5
2 hours after H.W.	043°	1·7	1·7	1·1
3 hours after H.W.	051°	1·2	1·2	0·8
4 hours after H.W.	072°	0·7	0·7	0·4
5 hours after H.W.	151°	0·6	0·6	0·4
6 hours after H.W.	187°	1·1	1·1	0·7

Residual Motion
0·45 knot towards 156°

At Sheerness

Mean Range for day (*from Tide Tables*)	17·3 ft.
Mean Spring Range	16·9 ft.
Mean Neap Range	10·9 ft.

(Both these come from *Table V* of the *Tide Tables*)

$$\text{Spring factor} = \frac{16{\cdot}9}{17{\cdot}3} = 0{\cdot}98$$

$$\text{Neap factor} = \frac{10{\cdot}9}{17{\cdot}3} = 0{\cdot}63$$

(*g*) Do not forget to give an indication of the reliability of these results. In this particular case the reliability is poor, and the figures can only give the mariner a general idea of what the tidal streams are likely to be doing.

In most cases, and provided the pitfalls described above are avoided, the reliability should be as good as that associated with the observations off Milford Haven, which are described in (i) above. The surveyor should never forget, however, that the method itself is bound to introduce errors, which will tend to be larger as the diurnal inequality of the tidal streams becomes greater.

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(24065) Dmd. 632765. K.40. 11/69. S.P. & S. **(Gp. 3319)**

TABLE FOR CONVERTING METRES TO FEET AND FATHOMS

Metres	Feet	Fms.	Metres	Feet	Fms.
1	3·281	0·547	51	167·323	27·887
2	6·562	1·094	52	170·604	28·434
3	9·843	1·640	53	173·885	28·981
4	13·123	2·187	54	177·165	29·528
5	16·404	2·734	55	180·446	30·074
6	19·685	3·281	56	183·727	30·621
7	22·966	3·828	57	187·008	31·168
8	26·247	4·374	58	190·289	31·715
9	29·528	4·921	59	193·570	32·262
10	32·808	5·468	60	196·850	32·808
11	36·089	6·015	61	200·131	33·355
12	39·370	6·562	62	203·412	33·902
13	42·651	7·108	63	206·693	34·449
14	45·932	7·655	64	209·974	34·996
15	49·213	8·202	65	213·255	35·542
16	52·493	8·749	66	216·535	36·089
17	55·774	9·296	67	219·816	36·636
18	59·055	9·843	68	223·097	37·183
19	62·336	10·389	69	226·378	37·730
20	65·617	10·936	70	229·659	38·276
21	68·898	11·483	71	232·940	38·823
22	72·178	12·030	72	236·220	39·370
23	75·459	12·577	73	239·501	39·917
24	78·740	13·123	74	242·782	40·464
25	82·021	13·670	75	246·063	41·010
26	85·302	14·217	76	249·344	41·557
27	88·583	14·764	77	252·625	42·104
28	91·864	15·311	78	255·906	42·651
29	95·144	15·857	79	259·186	43·198
30	98·425	16·404	80	262·467	43·745
31	101·706	16·951	81	265·748	44·291
32	104·987	17·498	82	269·029	44·838
33	108·268	18·045	83	272·310	45·385
34	111·549	18·591	84	275·591	45·932
35	114·829	19·138	85	278·871	46·479
36	118·110	19·685	86	282·152	47·025
37	121·391	20·232	87	285·433	47·572
38	124·672	20·779	88	288·714	48·119
39	127·953	21·325	89	291·995	48·666
40	131·234	21·872	90	295·276	49·213
41	134·514	22·419	91	298·556	49·759
42	137·795	22·966	92	301·837	50·306
43	141·076	23·513	93	305·118	50·853
44	144·357	24·059	94	308·399	51·400
45	147·638	24·606	95	311·680	51·947
46	150·919	25·153	96	314·961	52·493
47	154·199	25·700	97	318·241	53·040
48	157·480	26·247	98	321·522	53·587
49	160·761	26·794	99	324·803	54·134
50	164·042	27·340	100	328·084	54·681

Metres	Feet	Fms.
200	656·17	109·36
300	984·25	164·04
400	1312·34	218·72
500	1640·42	273·40
600	1968·50	328·08
700	2296·59	382·76
800	2624·67	437·45
900	2952·76	492·13
1000	3280·84	546·81
2000	6561·68	1093·61
3000	9842·52	1640·42
4000	13123·36	2187·23
5000	16404·20	2734·03
6000	19685·04	3280·84
7000	22965·88	3827·65
8000	26246·72	4374·45
9000	29527·56	4921·26
10000	32808·40	5468·07

Metres	Inches
0·10	3·937
0·20	7·874
0·30	11·811
0·40	15·748
0·50	19·685
0·60	23·622
0·70	27·559
0·80	31·496
0·90	35·433
1·00	39·370

Factors: 1 metre = 3·280839895 feet or 39·370078740 inches
= 0·546806649 fathoms

N.P.134 b (3)

ADMIRALTY MANUAL OF HYDROGRAPHIC SURVEYING

VOLUME TWO

CHAPTER 3

Sounding

1969

Published by

THE HYDROGRAPHER OF THE NAVY
TAUNTON, SOMERSET

TABLE FOR CONVERTING FEET AND FATHOMS TO METRES

Feet	Fms.	Metres
1		0·305
1·5	¼	0·457
2		0·610
3	½	0·914
4		1·219
4·5	¾	1·372
5		1·524
6	1	1·829
7		2·134
8		2·438
9	1½	2·743
10		3·048
11		3·353
12	2	3·658
13		3·962
14		4·267
15	2½	4·572
16		4·877
17		5·182
18	3	5·486
19		5·791
20		6·096
21	3½	6·401
22		6·706
23		7·010
24	4	7·315
25		7·620
26		7·925
27	4½	8·230
28		8·534
29		8·839
30	5	9·144
31		9·449
32		9·754
33	5½	10·058
34		10·363
35		10·668
36	6	10·973
37		11·278
38		11·582
39	6½	11·887
40		12·192
41		12·497
42	7	12·802
43		13·106
44		13·411
45	7½	13·716
46		14·021
47		14·326
48	8	14·630
49		14·935
50		15·240

Feet	Fms.	Metres
51	8½	15·545
52		15·850
53		16·154
54	9	16·549
55		16·764
56		17·069
57	9½	17·374
58		17·678
59		17·983
60	10	18·288
61		18·593
62		18·898
63	10½	19·202
64		19·507
65		19·812
66	11	20·117
67		20·422
68		20·726
69	11½	21·031
70		21·336
71		21·641
72	12	21·946
73		22·250
74		22·555
75	12½	22·860
76		23·165
77		23·470
78	13	23·774
79		24·079
80		24·384
81	13½	24·689
82		24·994
83		25·298
84	14	25·603
85		25·908
86		26·213
87	14½	26·518
88		26·822
89		27·127
90	15	27·432
91		27·737
92		28·042
93	15½	28·346
94		28·651
95		28·956
96	16	29·261
97		29·566
98		29·870
99	16½	30·175
100		30·480

Feet	Fms.	Metres
102	17	31·090
108	18	32·918
114	19	34·747
120	20	36·576
126	21	38·405
132	22	40·234
138	23	42·062
144	24	43·891
150	25	45·720
156	26	47·549
162	27	49·378
168	28	51·206
174	29	53·035
180	30	54·864
186	31	56·693
192	32	58·522
198	33	60·350
204	34	62·179
210	35	64·008
216	36	65·837
222	37	67·666
228	38	69·494
234	39	71·323
240	40	73·152
246	41	74·981
252	42	76·810
258	43	78·638
264	44	80·467
270	45	82·296
276	46	84·125
282	47	85·954
288	48	87·782
294	49	89·611
300	50	91·440
306	51	93·269
312	52	95·098
318	53	96·926
324	54	98·755
330	55	100·584
336	56	102·413
342	57	104·242
348	58	106·070
354	59	107·899
360	60	109·728
366	61	111·557
372	62	113·386
378	63	115·214
384	64	117·043
390	65	118·872
396	66	120·701
402	67	122·530
408	68	124·358
414	69	126·187
420	70	128·016

Feet	Fms.	Metres
426	71	129·845
432	72	131·674
438	73	133·502
444	74	135·331
450	75	137·160
456	76	138·989
462	77	140·818
468	78	142·646
474	79	144·475
480	80	146·304
486	81	148·133
492	82	149·962
498	83	151·790
504	84	153·619
510	85	155·448
516	86	157·277
522	87	159·106
528	88	160·934
534	89	162·763
540	90	164·592
546	91	166·421
552	92	168·250
558	93	170·078
564	94	171·907
570	95	173·736
576	96	175·565
582	97	177·394
588	98	179·222
594	99	181·051
600	100	182·880

Feet	Metres
700	213·360
800	243·840
900	274·320
1000	304·800

Fms.	Metres
200	365·760
300	548·640
400	731·520
500	914·400
600	1097·280
700	1280·160
800	1463·040
900	1645·920
1000	1828·800

Inches	Ft.	Metres
1	0·083	0·025
2	0·167	0·051
3	0·250	0·076
4	0·333	0·102
5	0·417	0·127
6	0·500	0·152

Inches	Ft.	Metres
7	0·583	0·178
8	0·667	0·203
9	0·750	0·229
10	0·833	0·254
11	0·917	0·279
12	1·000	0·305

Factors

1 Inch = 0·0254 metres
1 Foot = 0·3048 metres
1 Fathom = 1·8288 metres or 6 feet

N.P.134 b (3)

ADMIRALTY MANUAL OF HYDROGRAPHIC SURVEYING

VOLUME TWO

CHAPTER 3

Sounding

1969

Published by

THE HYDROGRAPHER OF THE NAVY

To be obtained from

Agents for the Sale of Admiralty Charts

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This Chapter supersedes the whole of Chapter X
and parts of Chapter XVII of the *Admiralty Manual
of Hydrographic Surveying* (1948 Edition)

Price 17s. od. net

*Printed in England for Her Majesty's Stationery Office
by The Campfield Press, St. Albans*

FOREWORD

This Chapter deals with all types of practical sounding. It has been assumed that the reader will already have Volume I of this work, to which reference is made as and when necessary.

The text has been written by Commander H. R. Hatfield, R.N., assisted by Lieutenant-Commander D. R. Benson, R.N. Acknowledgement is due to those many surveying officers and recorders who have, over a number of years, contributed to the techniques and ideas which are set out here.

G. S. RITCHIE
Rear-Admiral
Hydrographer of the Navy.

CHAPTER 3

Sounding

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CHAPTER 3 *Sounding*

Part 1 Echo Sounders; Leadlines; Sounding machines

1. Introduction

Sounding, which consists in determining depth and position simultaneously, is perhaps the most important part of the hydrographic surveyor's work. In so far as the fieldwork is concerned, it will occupy the greater part of his time; it will generally be the most arduous and sometimes the least interesting duty he has to perform.

Safe navigation demands an accurate knowledge of the depth of the sea, particularly in harbours and their approaches, where vessels may be compelled to use anchorages, channels and fairways in which the depths allow little margin for error. As the bed of the sea is hidden from view, its form can only be determined by obtaining systematic soundings over the whole water area of a survey. It is assumed, unless there are indications to the contrary, that the slope of the bottom is uniform in the spaces between adjacent lines of sounding, a postulate which has no strict justification; however, no better method than that of running systematic and evenly spaced lines of sounding has yet been devised, and it can at least be said that the results have on the whole been satisfactory. The possibility of the existence of irregularities dangerous to navigation between adjacent lines of soundings cannot lightly be dismissed, and sometimes it is necessary to supplement sounding by sweeping at some predetermined depth.

Modern inventions have done much to relieve the manual labour involved in sounding. Some of them, such as the echo-sounder, have improved the surveyor's chances of detecting unknown dangers. Electronic fixing systems make sounding possible even in low visibility. All these devices tend to increase output; they can also improve accuracy, provided, and only provided the surveyor is thoroughly conversant with their operation and limitations.

2. The Echo Sounder

a. General principles

It is most important to realise that an echo sounder does not, and cannot, measure depth. All echo sounders measure time—the time taken for a pulse of sound to travel from the transmitter to the sea bed and back. This time interval is then converted to depth by multiplying it by the velocity of sound in water, thus:

$$\text{Depth} = \tfrac{1}{2}vt$$

where t = time taken for pulse to travel to the sea bed and back,
and v = velocity of sound in water.

If the depth indicated by an echo sounder is to be correct, then in theory the measurement of t must be correct, and the value of v used in the calculation must equal the average velocity of sound in the water through which the pulse has travelled. In practice small errors in v can be compensated by introducing balancing errors into the measurement of t, so that the product vt remains a constant for any depth.

b. The nature of the echo pulse

The pulse of energy emitted into the water when an echo sounder transmits is in the form of a sound or compression wave. This pulse may vary in its frequency, duration and shape; it may be allowed to spread out equally in all directions from its point of generation, or it may be concentrated into a beam by a reflector. The qualities of any particular echo sounder will depend very largely upon how these variables are combined. The repetition rate of the pulse may also be varied to suit a particular requirement.

(i) Pulse frequency. Variation of the frequency of the pulse produces great changes in the qualities of an echo sounder.

Low frequencies, almost in the audible band, will transmit energy efficiently over long distances. Their power will not be quickly reduced by solid objects in the water, such as sand in suspension or plankton, and they will penetrate quite deeply into the sea bed, producing echoes off the underlying layers. On the other hand a very large reflector will be required if they are to be concentrated into any sort of a beam, and most of the other equipment necessary to their production will be large and cumbersome.

High frequency pulses can be produced by light and compact electronic equipment. A comparatively small reflector will concentrate them into a narrow beam. Their power will, however, be relatively quickly reduced in water, and they will not penetrate deeply into the sea bed.

Most modern echo sounders generate fairly high frequency pulses, the criterion being that provided the range of the set is satisfactory, the frequency should be as high as possible.

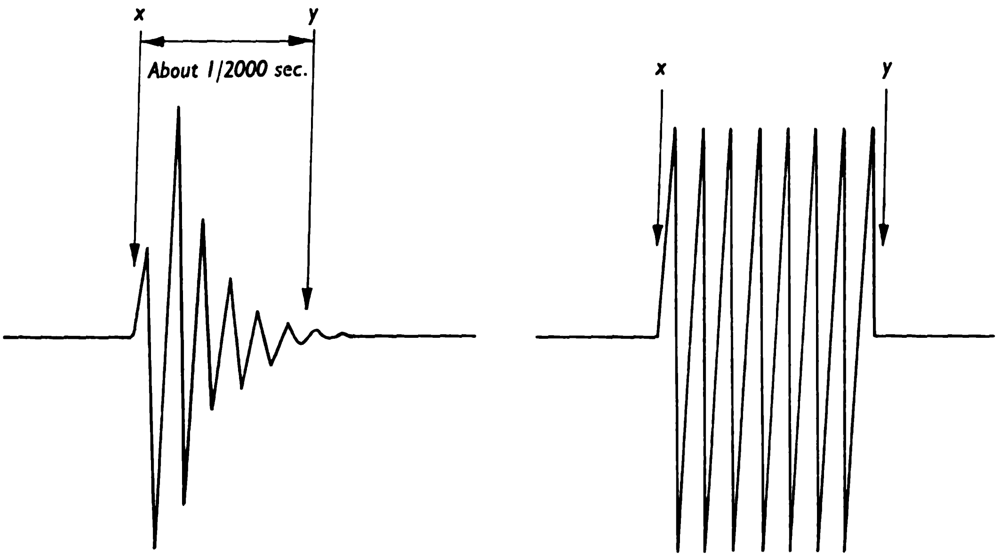
The following table shows how the pulse frequency varies in typical sets designed for different purposes:

TYPE OF SET	PULSE FREQUENCY
Boat's, shallow water	16 kc/s
Ship's, general purpose	14 kc/s
Ship's, deep water	10 kc/s

(ii) Pulse duration and shape. Fig. 3–1(a) shows the shape of the transmission pulse generated by a typical general purpose echo sounder. At the point *x* the transducer is energised by a powerful magnetic field of very short duration. It then oscillates at its natural fequency, emitting a pulse of sound into the water, but the oscillations die down rapidly, until at *y* they have virtually ceased. The practical pulse-length in this case would be about 1/5,000 of a second, measured to the point at which the oscillations reach about half their initial amplitude.

This type of pulse is comparatively easy to produce. It cannot contain very much power, but nevertheless will produce an echo from a bottom over 1,000 fathoms deep under good conditions. Since sound travels about one foot in water in 1/5,000 second, an echo sounder having a pulse length of this type will have good definition.

Fig. 3–1(b) shows the shape of the transmission pulse generated by a typical powerful deep water echo sounder. Energy is supplied to the transducer at the point *x*, and maintained until the point *y*. The transducer oscillates at its natural frequency, but the oscillations do not die down, and the pulse of sound emitted into the water contains much more power than that produced by the damped oscillations referred to above. In practice the time interval between points *x* and *y* in the diagram can be varied between about 1/1,000 second and 1/25 second. Under good conditions, echoes may be obtained from a bottom over 5,000 fathoms deep, with a fairly long pulse. An



(*a*) *Damped Oscillations* (*b*) *Undamped Oscillations*

Fig. 3–1

echo sounder producing a long pulse will have relatively poor definition, since in 1/25 second sound will travel nearly 200 feet.

(iii) The echo beam. It would be very wasteful to allow the transmission pulse of an echo sounder to spread out equally in all directions. For this reason all transmitting units are fitted with reflectors, which concentrate the energy into a beam.

The shape of this beam depends on the diameter of the reflector and the frequency of the pulse. The greater the diameter of the reflector, and the higher the frequency of the pulse, the narrower and more concentrated will be the beam.

Fig. 3–2 shows the shape of the beam produced by a typical general purpose echo sounder. It is very similar to that produced by the headlamp of a car. Most of the energy is concentrated into the main lobe, which may for all practical purposes be considered to be a cone whose apex angle is about 20°. The energy of the beam does not suddenly vanish at the edges of the main lobe; in the diagram these have been drawn, quite arbitrarily, to define a surface on which the power is about half that in the centre of the beam. Outside the main lobe power falls away rapidly, but there are two side lobes where the power increases again, centred about axes approximately 30° either side of the main axis. These side lobes serve no useful purpose and can at times produce false echoes, but no reflector has yet been devised that will concentrate the energy into the main lobe alone. Many transmitting units produce several pairs of side lobes, in addition to the main lobe, but provided they are well designed by far the greater part of the available power will be concentrated into the main lobe.

(iv) Choice of frequency; pulse length and shape; beam width. The damped pulse illustrated in Fig. 3–1(a) is very much easier to produce than the undamped pulse shown in Fig. 3–1(b). For this reason damped pulses are generated by all echo sounders unless sheer power is an important requirement. Most deep sea echo sounders will produce undamped pulses if required, and the power of the undamped pulse is usually very necessary when depths are greater than 2,500 fathoms.

A long pulse contains more energy than a short one. Some of its energy is also more

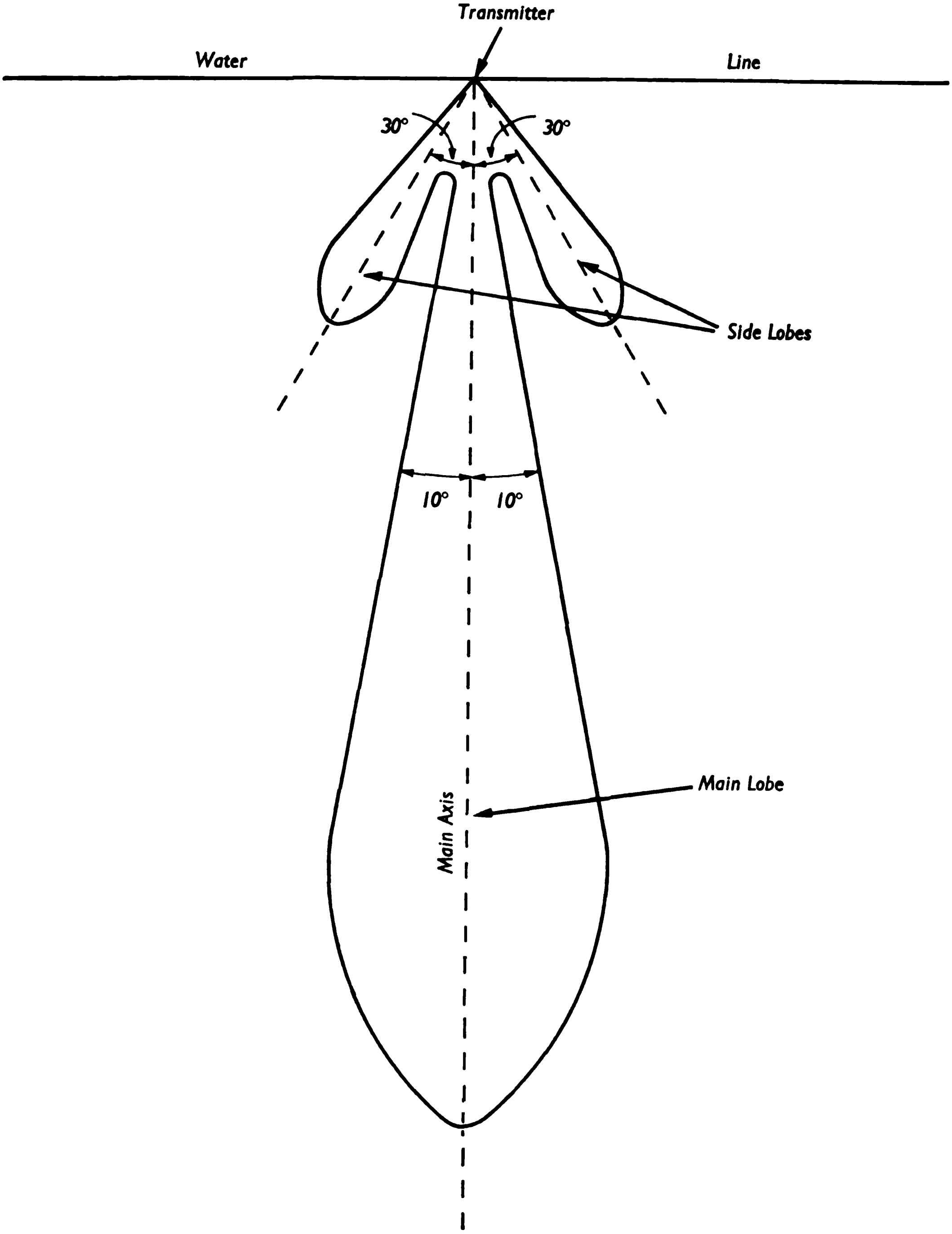


Fig. 3–2

likely to proceed in the required direction (vertically downwards) from a rolling and pitching ship. For these reasons long pulses may be necessary when sounding in deep water or when the ship is rolling or pitching. Long pulses impair definition, and therefore they should not be made longer than is necessary.

A high frequency, short pulse, narrow beam echo sounder might be very suitable for work with a dredging project in sheltered waters. It would give excellent definition. However, the high frequency would limit its working range, and the narrow beam width and short pulse would make it very susceptible to loss of echo, unless the water was very calm or the transmitting and receiving units were stabilised.

A typical deep sea echo sounder might well have facilities for producing an undamped pulse as long as 1/25 second. Its frequency would almost certainly be 10 kc/s or less, giving it a long range. It would have a wide beam width (the apex angle of the main lobe might well be 40°) to overcome the effects of ship movement. Most of these attributes would tend to make it large, complicated and expensive.

Most general purpose echo sounders are designed as a compromise. A frequency of about 15 kc/s, damped pulses of about 1/5,000 second, and a main lobe apex angle of about 20° will give very reasonable results, without making the equipment too large and expensive.

It is important to note, however, that it is not possible to combine all the desirable features to their greatest extent in one set.

c. The timing device; phasing; 'once round the clock'

It would be quite possible to measure the time taken for an echo pulse to proceed to the sea bed and back with a stopwatch, and to convert this time to depth using the formula in Section **2a.** All echo sounders suitable for hydrographic surveying measure the time interval themselves, and convert it into 'depth' automatically. As will be seen, this 'depth' may or may not be correct, depending upon how the equipment is adjusted.

There are many ways of presenting instantaneous depth. The pointer of an ammeter or galvanometer may indicate it against a scale; or a flashing lamp on a rotating arm may do the same thing against a more open scale. However, the surveyor's requirements are not fully met unless he has a permanent record of depth plotted against time, and this record is at present most easily produced by some sort of electromechanical recorder.

(i) The timing device in a typical recorder. One of the functions of the recorder is to measure the time taken for an echo pulse to proceed to the sea bed and back, and to convert this time to depth. To do this, it must first initiate the transmission of the echo pulse.

Fig. 3–3 shows part of a typical recorder. The stylus rotates on the end of an arm about the spindle *A*. The electronic circuits of the echo sounder are so designed that when the transmission pulse is generated, an electric current passes from the stylus to a metal backing plate through sensitised paper. The passage of the current leaves a mark on the paper; this is drawn from a roll slowly downwards over the backing plate, or platen. When the echo from the bottom, or indeed any other sonic signal of the correct frequency, is received in the electronic circuits, current will again pass from the stylus through the paper, leaving another mark.

Suppose that the spindle *A*, to which the stylus is rigidly attached, is driven by an accurately governed electric motor, and makes one revolution in 2·195122 seconds, and that the speed of sound in water is 820 fms/sec. During one revolution of the stylus an echo pulse will travel

$$820 \times 2{\cdot}195122 = 1{,}800 \text{ fathoms},$$

that is, it will proceed to the sea bed 900 fathoms deep and back again.

Therefore, is the phase dial circumference, which corresponds to one revolution of the stylus, is divided into 900 units, measurements of time (one revolution = 2·195122 seconds) will be converted directly into depth (one revolution = 900 fathoms). But this will only be done if the speed of sound in water is 820 fms/sec.

Suppose now that the speed of sound in water is 800 fms/sec. and that the stylus

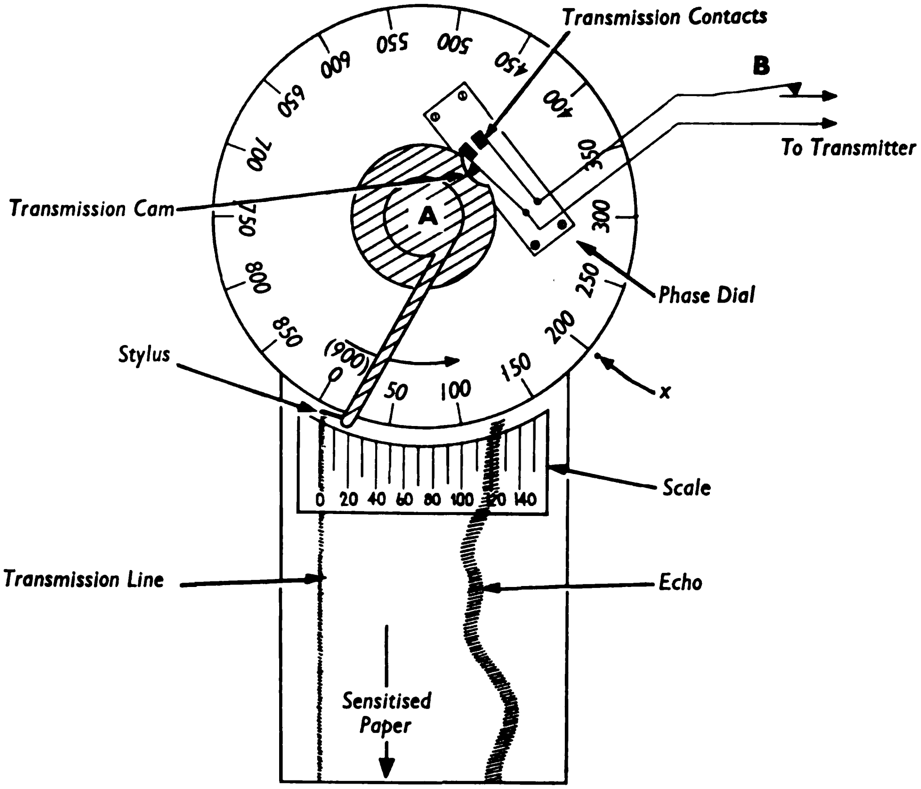


Fig. 3–3

still rotates once in 2·195122 seconds. Then one revolution of the stylus will be equivalent to a depth of

$$\frac{800 \times 2\cdot195122}{2} = 878 \text{ fathoms.}$$

This figure will be most inconvenient, since the phase dial is divided to show 900 fathoms in one revolution. However, if the speed of spindle *A* is reduced so that it makes one revolution in 2·2500 seconds, one revolution of the stylus will be equivalent to a depth of

$$\frac{800 \times 2\cdot2500}{2} = 900 \text{ fathoms}$$

and the phase dial markings may once more be used to convert time directly into depth.

This relationship between the speed of rotation of the stylus, the speed of sound in water, and the value in fathoms of one revolution of the stylus, is most important. It will be discussed further in Section 4 of this chapter.

In Fig. 3–3 the stylus, which is rotating anti-clockwise once in 2·195122 seconds, has just reached the zero marks on the phase dial and scale. At this instant the transmission cam opens the transmission contacts;* the echo pulse is generated and transmitted a fraction of a second later. The electronic components in the echo receiver detect this pulse and cause a current to pass from the stylus to the tank face, so that a mark is made on the sensitised paper. This mark, and its fellows from earlier and later transmissions, form the transmission line.

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* In some sets it may well *close* the contacts at this instant. The result is the same.

While the echo pulse is making the journey to and from the sea bed, which in this case is 120 fathoms deep, the stylus will be proceeding across the paper towards the right. Provided, and only provided, the speed of sound in the water in question is 820 fms/sec., the stylus will be opposite the 120 mark on the scale when the echo returns, and a second mark, indicating depth, will be made on the paper. If the speed of sound in water were less than 820 fms/sec., the stylus would have passed the 120-fathom mark by the time the echo returned, and a greater depth than actually existed would be recorded; conversely, had the speed of sound been greater than 820 fms/sec., the depth recorded would have been too small. These marks indicating depth, when made on the moving sensitised paper, form the echo trace, a permanent record of depth plotted against time.

In Fig. 3–3 the stylus rotates once in 2·195122 seconds, and the measurements of depth are in fathoms. If it were made to rotate at six times this speed, everything else remaining the same, depths would automatically be recorded in feet.

In practice it is possible to move the transmitting contacts slightly relative to the phase dial. This movement will alter the instant of transmission relative to the depth scale; the transmission line can be set anywhere between depths of 0 and perhaps 30 or 35 feet. Most surveyors set it so that true depths are indicated on the record in a way described in Section 4, which deals with calibration. In merchant vessels the transmission line is very often set to zero, so that indicated depths are below the transducer, which is probably very close to the keel.

If a recorder has more than one speed, i.e. it measures feet and fathoms, or metres and metres × 10, it will be necessary to have two sets of transmitting contacts, since otherwise it will not be possible to set the transmission lines correctly in both speeds.

(ii) Phasing. In Fig. 3–3 the phase dial has been graduated around its circumference so that 900 fathoms or feet equals one revolution of 360°. Therefore:

$$\text{150 fathoms or feet} = 360^\circ \times \frac{150}{900} = 60^\circ$$

$$\text{and 100 fathoms or feet} = 360^\circ \times \frac{100}{900} = 40^\circ$$

Imagine that in the figure the stylus is rotating in the fathoms speed, and the depth is 200 fathoms. The transmission line is made in the usual way. Suppose that it appears against the zero marks on the phase dial and scale. When the echo returns the stylus will have reached the point x, opposite the 200-fathom mark on the phase dial. It will not mark the sensitised paper, since at x there is no paper to mark.

Suppose now that the phase dial, to which the transmission contacts are firmly secured, is rotated 40° in a clockwise direction, and locked in this position. The transmission pulse will occur at the same instant relative to the phase dial (as the stylus passes the zero mark); but it will occur 40° (100 fathoms) earlier relative to the scale and sensitised paper. The transmission line will disappear off the left hand side of the paper; the 200-fathom echo, which was at the point x, will appear opposite the 100-fathom mark on the scale; and all echoes will, when read off against the scale, appear to be 100 fathoms shallower than they really are. However, since the phase dial has been turned 100 fathoms in a clockwise direction, the figures between 100 and 250 will now appear above the scale, and remove any doubt as to the correct value of the recorded depth.

The phasing of this particular recorder can be adjusted in nine steps, each of 40° or 100 feet or fathoms. In this way the full working range of the recorder may be used. Note that each phase overlaps its neighbours by 50 feet or fathoms.

It may happen that when the recorder is switched on, no echo appears, although the set is known to be transmitting correctly. In this case it is very likely that the echo is returning after the stylus has left the sensitised paper. It must be searched for by phasing. If there is any doubt as to its position it will generally be safer to start with the zero phase (the transmission line near the zero mark on the scale), and work upwards. Note that in the greatest phase (+800) the transmission line will appear opposite the 100-fathom mark on the scale; it must not be confused with a possible echo.

Most rotary recorders have a phasing device similar to the one described above. The phasing steps may well vary, however, depending on the design of the equipment, and it will always be prudent to make quite certain what they are before using a particular set.

It is possible to fit the wrong phasing dial or scale to a recorder, particularly during routine overhauls. To the unwary, most phasing dials and scales look much alike, but if they are wrongly graduated, the consequences of using them may be diastrous. It will be a wise precaution, on first using a set, to check the relationship between the speed of rotation of the stylus, the speed of sound in water, and the value in fathoms of one revolution on the phase dial, as described in Section **2c(i)**. The scale should also be checked against the phase dial.

(iii) 'Once round the clock.' Imagine that the vessel fitted with the recorder illustrated in Fig. 3–3 is steaming over a bottom which is 1,000 fathoms deep, and shoaling fairly rapidly, when the echo sounder is first switched on in the fathoms speed; the phase dial is in the position illustrated.

The first transmission pulse will leave as the stylus passes the zero mark on the scale. Since one revolution of the stylus is equivalent to only 900 fathoms, this first transmission pulse will still be on its journey to and from the bottom when the second pulse is generated. It will arrive shortly afterwards, and cause the stylus to make a mark opposite the 100-fathom graduation on the scale (1000 − 900 = 100). Thereafter, each transmission pulse will take more than one revolution of the stylus to complete its journey, and indicate an apparent depth 900 fathoms too shallow. As the bottom is shoaling fairly rapidly, the echo trace will approach the transmission line and proceed right through it, and the unitiated observer will get the impression that he is running aground. Without any external evidence to the contrary, the mariner would in fact be very wise to assume he was running into danger, should he be presented with a trace similar to that described above. There is no apparent difference at all between a trace 'once round the clock' and a normal one. This phenomenon is virtually built into powerful, modern, echo sounding sets, where the pulse will fathom depths far greater than those equivalent to one revolution of the stylus, under good conditions. It is possible for a powerful echo sounder to produce echoes two or even three times 'round the clock'. An echo sounder with a recorder similar to that illustrated has been known to produce an apparent depth of 300 fathoms when the actual depth was 2,100 fathoms (2100 − 2(900) = 300).

The following measures will generally determine whether a recorded depth is genuine or 'once round the clock', although common sense is probably the most powerful weapon in the doubtful mariner's armoury. They are listed in the order in which they should be applied:

(*a*) If sounding in the feet or fast speed, switch to the fathoms or slow speed. The correct depth should then be obvious.

(*b*) If the recorder is fitted with an 'Open-Circuit Transmission'* switch similar to

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* When this special switch is not fitted, the same effect can be achieved on some echo-sounders by using the recorder main switch. This should be switched on and off, so as to embrace one transmission only. The success of this method depends very much on the design of the equipment, and it is by no means infallible.

B in Fig. 3–3, break the switch for at least five revolutions of the stylus arm (the more the better). Then make the switch just before the stylus reaches the transmitting point, and break it again soon after the transmission has taken place. This will allow one transmission only to leave the set, and the number of revolutions of the stylus before the return of the echo can be counted.

(*c*) Switch on another echo sounder if one is available; preferably one with a greater range and slower stylus speed.

(*d*) If all else fails, stop the vessel and obtain a wire or hand lead sounding.

d. The transmission unit

The transmission unit of a typical echo sounder almost always contains three parts: the signal generator, the switching unit and the transducer.

The signal generator generates pulses of electrical energy. It is switched on and off as necessary by the transmission contacts shown in Fig. 3–3, probably through an electrical relay of some sort.

The switching unit, which will usually be an electromechanical parallel plate contactor or an electronic gas discharge tube, connects the output from the signal generator across the terminals of the transducer at the correct instant. Again, it will be controlled by the transmission contacts shown in Fig. 3–3. If undamped pulses are being generated by the signal generator, this switching unit will be replaced by pulse control and power amplifier units. If an echo sounder develops very little power, a separate switching unit may not be necessary, since the transmission contacts themselves may be able to handle the current.

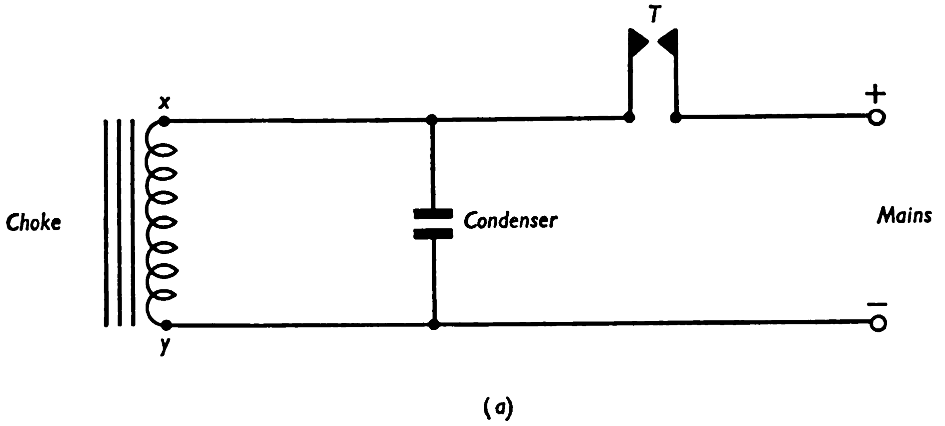
The transducer receives the pulse of electrical energy generated by the signal generator, via the switching unit, and converts it into a pulse of sound energy. The sound waves are concentrated into a beam by the reflector. Transducers may be of the magneto striction or piezo electric type, depending on the design of the equipment, and in modern echo-sounders they may well be assembled in multiple arrays, which concentrate the energy into a narrow beam in much the same way as a large reflector.

The design of echo sounding sets offers almost unlimited scope for the ingenuity of the manufacturer. No two sets are alike, and no attempt will be made here to describe any particular set. All transmitters must have signal generators and transducers, and most will have switching units as well. If the principles outlined below are grasped and understood, the hydrographic surveyor should be able to apply them to any set he may have to use.

(i) Choke capacity signal generators; contactors. Choke capacity signal generators are robust and simple. They can be designed to operate from a low voltage (12 to 24 volts) supply. They generate heavily damped pulses only, and for this reason cannot produce very much power.

Fig. 3–4(a) shows a simple choke capacity circuit which is fed from the mains through *T*, the transmission contacts in the recorders. Fig. 3–4(b) shows the voltage across the condenser (between the points *x* and *y*) plotted against time. Referring to these two figures, the circuit behaves as follows:

The switch *T* was made some time before the instant *A*; between *A* and *B* the condenser is charged up to the mains voltage, in this case about 100 volts. At the instant *B* switch *T* is broken, and the choke capacity circuit produces a powerful inductive 'kick'. The voltage between points *x* and *y* falls to zero, and then about 1/60 second later, at the point *C*, reaches a very high voltage indeed in the opposite sense to that at *B*. In this case it reaches 2,500 volts. Left to itself the choke capacity circuit would oscillate at its natural frequency, as shown in Fig. 3–4(b), until all the energy had been absorbed in the resistance of the circuit. However, if at the instant *C* the points *x* and *y* are connected across the terminals of the transducer, and provided the design of the unit is correct, virtually all the energy contained in the choke



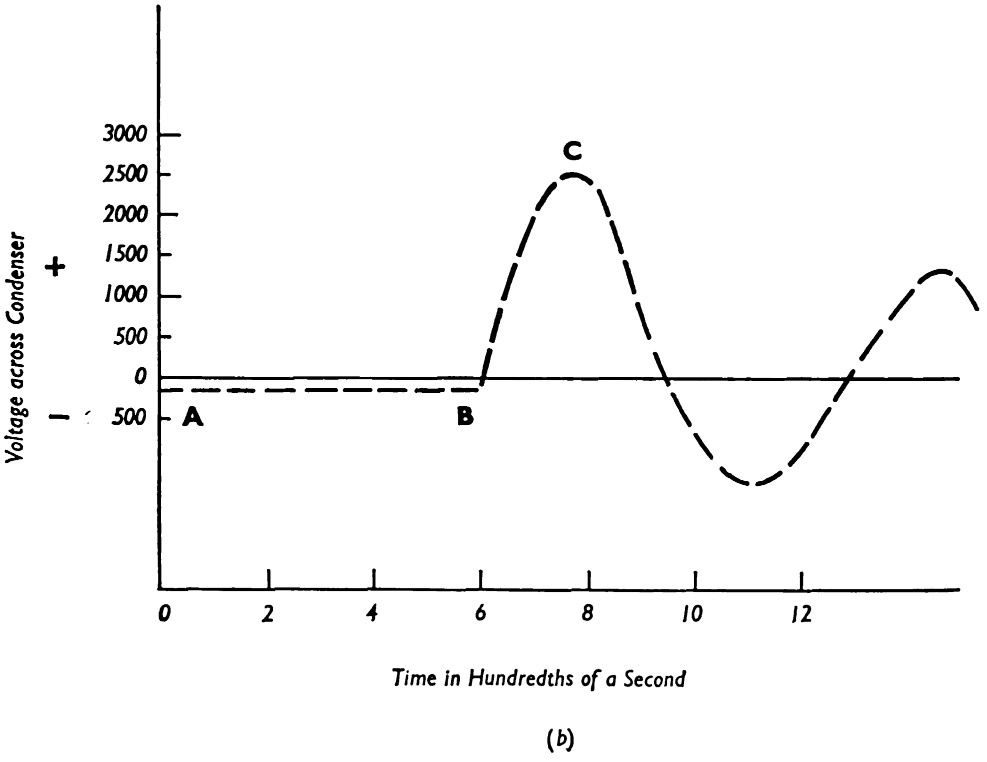


Fig. 3–4

capacity circuit will be transferred to the transducer, causing it to emit a pulse of damped acoustic energy at its resonant frequency.

Fig. 3–5 shows, in simplified form, a typical choke capacity signal generator, *LC*, which is controlled by the transmission contacts *T*, and connected to the transducer and power supplies as necessary by the parallel plate contactor units *P*, *A* and *B*.

For the greater part of the rotation of the stylus in the recorder the transmission contacts will be made. Current will flow through the solenoid *S*, and the moving plate *P* will be pulled into contact with *A*. This will place the mains voltage across *L* and *C*; a current will flow through *L*, and *C* will charge up.

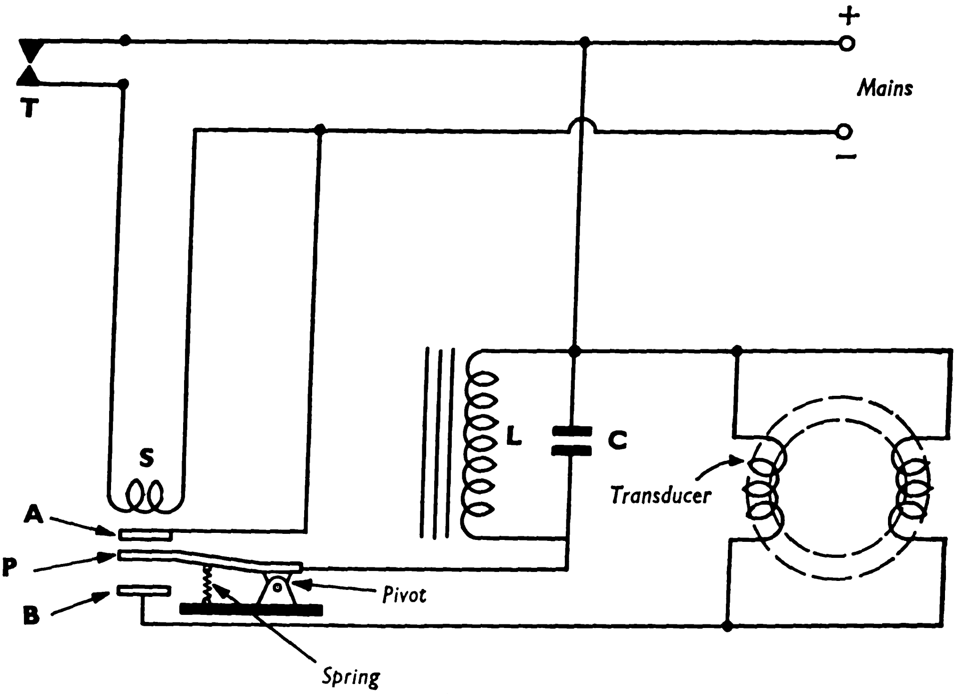


Fig. 3-5

Just before the stylus reaches the point at which transmission is to take place, contacts *T* are broken. The moving plate *P* will fall away from *A*, and move towards *B* under the influence of the spring. At this instant *L* and *C* will begin to generate a powerful inductive kick. Matters are so arranged that the voltage across *C* reaches a maximum just as the plate *P* makes contact with *B*. This puts the transducer windings in circuit with *L* and *C*, and a damped oscillatory current flows until all the energy stored in *C* has been dissipated. The design of the circuit is such that most of this energy passes between *C* and the transducer windings, and very little is wasted in the choke *L*. Transmission takes place when *P* makes contact with *B*; this will be a fraction of a second after the transmitting contacts *T* open.

For this arrangement to work efficiently the time taken for *P* to move from *A* to *B* must be exactly equal to the time taken for the inductive kick to reach its maximum voltage. In practice the contactor unit is designed so that it may be adjusted in the field to achieve this object. The adjustment is rather critical in most units.

(ii) Pure capacity signal generators; gas discharge valves. Fig. 3-6 shows, in simplified form, the electrical circuit of a typical pure capacity signal generator, which discharges through a gas discharge valve. Circuits of this type will produce damped pulses of greater power than those described in (i) above. They have no moving parts, except the transmission contacts in the recorder, and are simple to adjust.

The circuit depends entirely on the action of the gas discharge valve *V*. This is generally filled with a vapour, such as mercury or neon. Suppose that a voltage of about 1,500 volts is applied between the anode and cathode of this valve, and that the voltage on the grid is zero. The valve will behave as an insulator, and no current will flow between anode and cathode. However, if the voltage on the grid is raised momentarily above a certain minimum value, which depends on the design of the valve, the vapour inside the valve will ionise (the valve will actually light up like a mercury vapour or neon lamp), the resistance between anode and cathode will drop to virtually nothing, and the valve will become an extremely efficient conductor of large currents. If now the voltage on the grid is removed, the valve will remain ionised and conducting, until the voltage between the anode and cathode drops to the cut-off value, which will be far less than the original 1,500 volts. The valve will then shut off as suddenly as it started to conduct.

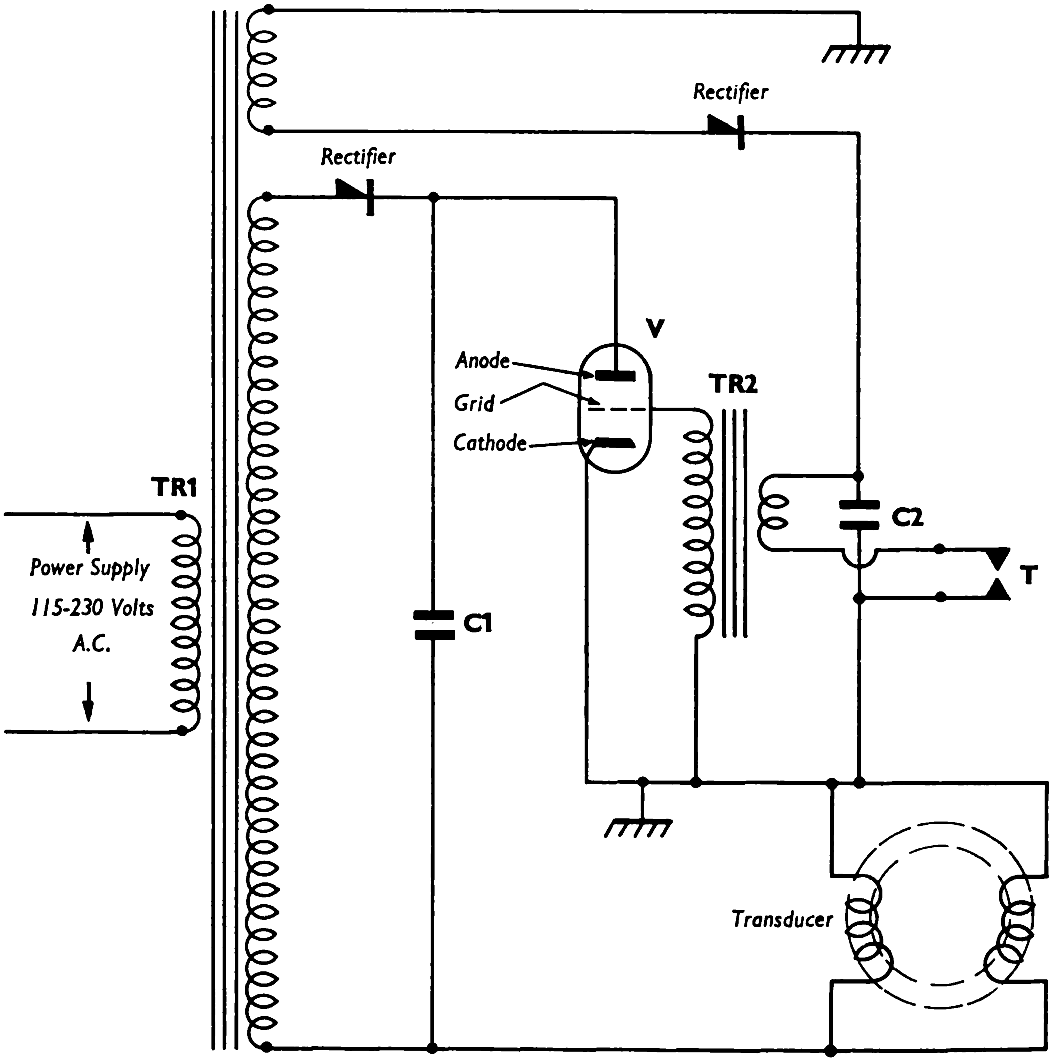


Fig. 3–6

The grid voltage necessary to cause the valve to conduct is too great to handle directly across the transmission contacts *T* in the recorder. It is therefore necessary to introduce *C2* and *TR2*, which together act in the same way as a relay.

For the greater part of the rotation of the stylus in the recorder, the transmission contacts *T* will be open. A.C. power supplies from a rotary converter will charge the large condenser *C1*, through the transformer *TR1* and a rectifier, to a d.c. voltage which may be anything up to about 1,500 volts. Note that this voltage will appear across the anode and cathode of the valve, but that no current can flow, since the valve is shut off. At the same time a smaller winding on transformer *TR1* will charge the small condenser *C2*, through a rectifier, to a d.c. voltage of anything between about 12 and 350 volts.

Just before the stylus reaches the point at which transmission is to take place, contacts *T* are made. Condenser *C2* discharges through the primary winding of the step-up transformer *TR2*; a high voltage is developed across the secondary winding of this transformer; this raises the voltage on the grid of *V* above the critical value necessary to ionise the gas in the valve. The valve ionises, and *C1* is discharged through the windings of the transducer; the valve will shut off as soon as its anode voltage drops below a certain level, and the discharge is therefore not oscillatory. However, the transducer oscillates at its own natural frequency. Transmission takes place when the valve *V* ionises; this will be a fraction of a second after the transmitting contacts *T* close.

The gas discharge valve forms a more efficient switching unit than a contactor when a lot of power has to be handled. Since it has no moving parts, and no metallic contacts, there can be no sparking and pitting to spoil a critical adjustment. For these reasons it is fitted in most modern sets of medium and high power.

In practice, circuits are far more complicated than the one shown in Fig. 3–6. However, principles of operation will almost always be similar to those described above.

(iii) Continuous wave signal generators; pulse control units. Continuous wave signal generators produce undamped pulses of comparatively high power. They are, in effect, small radio transmitters working at a very low frequency. Of their very nature they are bound to be more complicated and bulky than the signal generators described in (i) and (ii) above, but when sounding in really deep water it is necessary to accept these undesirable qualities in order to obtain the power that is required.

Fig. 3–7 shows the general arrangement of a typical continuous wave signal generator. When the echo sounder is switched on, the master oscillator produces a continuous radio signal at the correct frequency. This is passed on to the first stage amplifier via the pulse control unit, which acts as a switch in very much the same way as the gas discharge valve and contactor units referred to above. From here the signal passes through several power amplification stages before being applied to the transducer windings in the usual way. The design of the master oscillator, first stage and power amplifier units follows normal radio practice and need not be enlarged on here.

The heart of the whole unit, as it concerns the hydrographic surveyor, lies in the pulse control unit. Referring to Fig. 3–7 this behaves in the following manner:

For the greater part of the rotation of the stylus in the recorder the transmission contacts *T* will be made. The mains voltage between *x* and *y* will be shorted out through the resistance *R1*, and virtually no current will flow through the solenoids *S1* and *S2*. Relay *A* will be held in the open position by its spring, and relay *B* will be held in the closed position by a similar spring. Since both these relays must be closed before the master oscillator is connected to the first stage amplifier, the latter will not oscillate, although the master oscillator is doing so.

Just before the stylus reaches the point at which transmission is to take place, contacts *T* are broken. This puts the full mains voltage across the solenoids *S1* and *S2*. Depending on the values of *R1* and *C1*, it will take a fraction of a second for the current in *S1* to build up sufficiently to pull on relay *A* against the action of its spring. When *A* closes the circuit between the master oscillator and the first stage amplifier will be completed, and transmission will commence. The power amplifier will feed the transducer windings with undamped oscillations similar to those shown in Fig. 3–1.

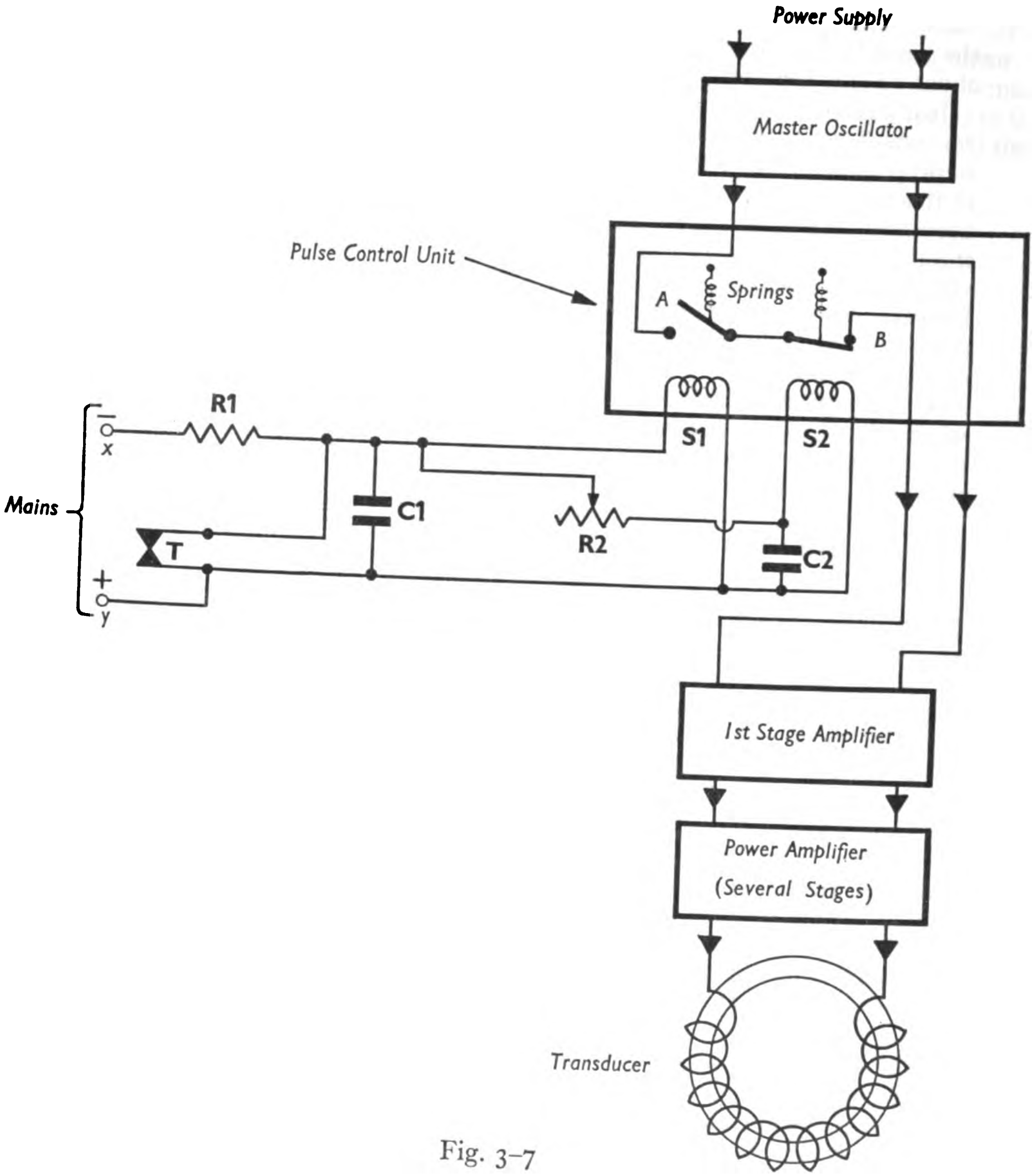


Fig. 3-7

Although the mains voltage is applied across solenoid *S2* at the same instant as *S1*, the current passing through it will build up more slowly, since it must pass through *R1* and *R2* and charge *C2* as well as *C1*. Depending on the values of *R2* and *C2* the solenoid *S2* will break relay *B* a short time after relay *A* was made. This will open the circuit between the master oscillator and the first stage amplifier, and transmission will cease. The time interval between relay *A* making and relay *B* breaking can be altered by adjusting the variable resistance *R2*, thus controlling the pulse length. In a typical deep sea echo sounder it is possible to vary the pulse length between about 1/1000 second and 1/25 second.

(iv) Frequency modulated signal generators. All the signal generators described in Sections **(di)** to **(iii)** above produce either amplitude modulated or unmodulated signals. That is to say, the frequency of their signals remains fixed, whilst the amplitude varies, or remains fixed also.

This need not necessarily be so. For some specialised uses echo sounder transmitters may be frequency modulated; the amplitude of the transmitted signal will generally remain fixed, but its frequency will vary with time.

No frequency modulated echo sounder has to date been used in the Royal Naval hydrographic service, and it seems likely that the requirements of chart makers of the future will be met by developments of the amplitude modulated or unmodulated sets which are in use at the present time.

e. Transducers

Transmitting and receiving transducers are physically interchangeable. However, they perform very different roles, and it is important that a transmitting circuit should never be connected to a receiving transducer, and vice versa, unless the implications of such a changeover are fully understood. It is quite possible to use the same transducer for transmitting and receiving, but then an additional switching unit would be necessary.

Transducers may operate either by magneto striction or by the piezo electric effect. The former is preferred by most British manufacturers, but many foreign makers adopt the latter.

(i) Magneto striction transducers. Fig. 3–8 shows a typical magneto striction transducer; to work efficiently it needs a large current at a moderate voltage; it will handle a lot of power if it is designed properly, but cannot be made to generate very high frequency sound waves. It consists of a stack of thin annular rings made of nickel, held together by an insulated toroidal winding of thick flexible wire threaded through perforations in the rings and the large central hole.

MAGNETO-STRICTION TRANSDUCER

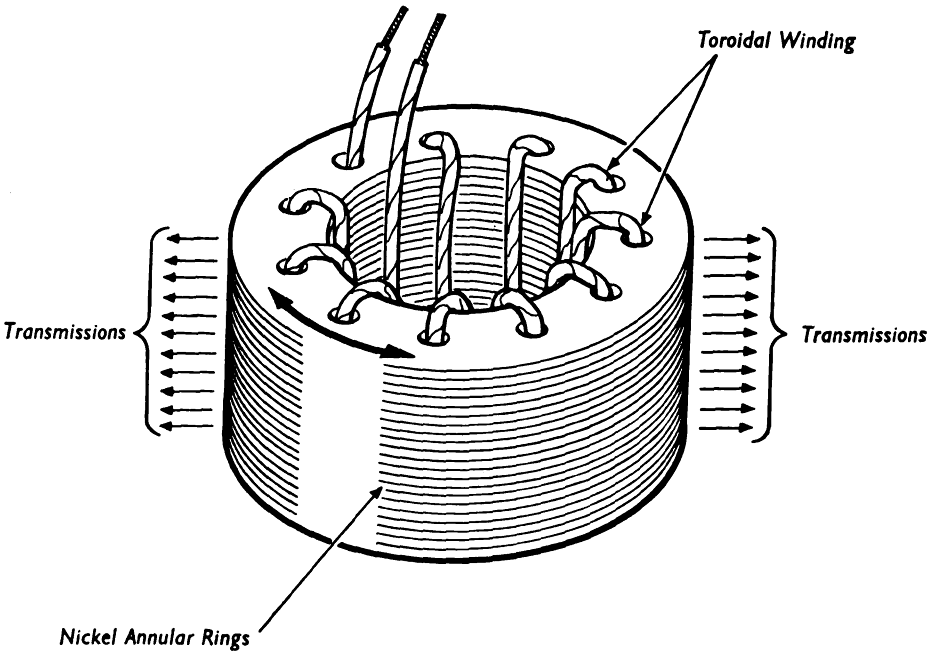


Fig. 3–8

If a steady current or d.c. pulse flows through the winding, it will induce a magnetic field in the nickel, and cause the rings to contract in the direction indicated by the thick arrow. When the current is switched off, the rings will return to their original dimensions, oscillating as they do so at their natural frequency, in the same way as a tuning fork vibrates when struck. If an alternating current is applied to the winding, the rings will contract and expand in step with the rise and fall of the current. The amplitude of this movement will be greatest when the frequency of the applied current is either half or the same as the natural frequency of the rings, depending on the design of the equipment. A circumferential contraction of the rings must produce an associated radial contraction; sound waves are therefore transmitted radially in all directions, as shown by the light arrows in the figure.

The amplitude of the contractions in the rings depends in part on the amount of magnetism induced in the nickel, and hence on the magnitude of the d.c. pulse or current, or amplitude of the alternating current. If these currents are large enough to saturate the nickel magnetically, increasing them further will not increase the magnitude of the contractions in the rings; greater transmitted power can only be obtained by increasing the size of the nickel stack, so that it no longer becomes completely saturated.

Fig. 3–9 shows a typical magneto striction transducer fitted in the bottom of a ship. It is housed inside a conical, or sometimes parabolic reflector, between whose double walls a layer of air is trapped, very often in the form of bubbles in sponge rubber. Both of them are supported inside a metal tank, which is fixed to the ship's bottom and filled with fresh water.

When the transducer oscillates, sound waves proceed out horizontally from it, strike the reflector, where they are reflected vertically downwards, and proceed

MAGNETO-STRICTION TRANDSDUCER ASSEMBLY

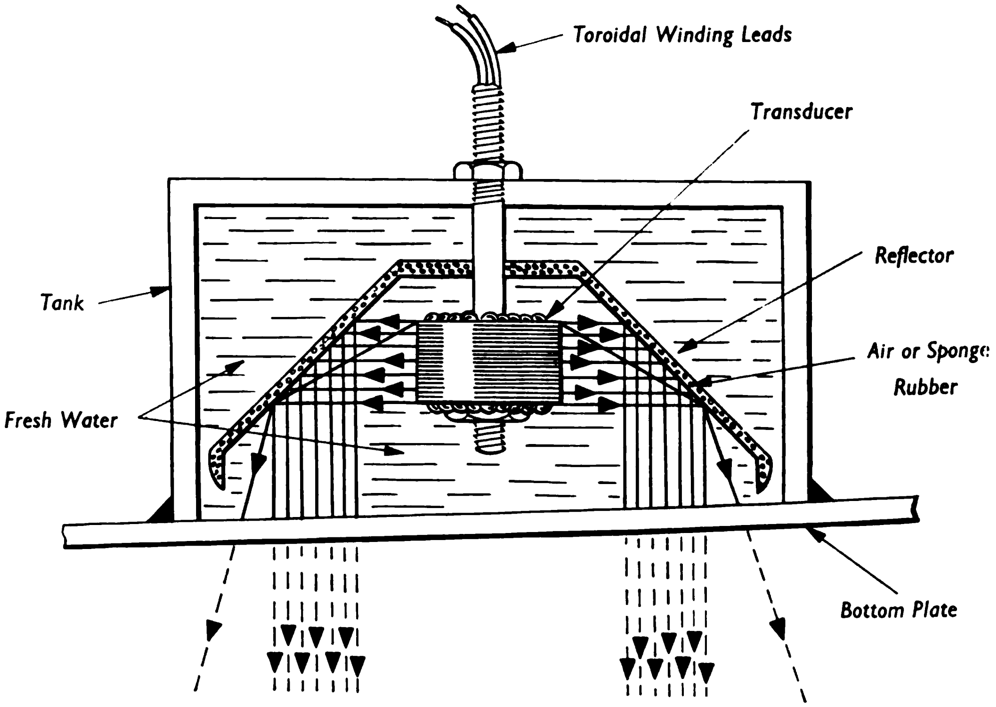


Fig. 3–9

through the ship's bottom plate to the sea bed. The waves fan out as indicated in the diagram. Returning sound energy travels over the reverse path, and on striking the receiving transducer causes it to oscillate. A great deal (sometimes well over 80%) of the energy striking the ship's bottom plate fails to emerge from the other side; this plate acts as a fairly good reflector, unless it is extremely thin or very thick indeed.* Despite this grave drawback magneto striction transducers can still be designed to generate enough power to be efficient, even when working through quite a thick plate. This means that they can be fitted inside a ship without piercing the hull and that replacement can be made without docking.

(*a*) MAGNETO STRICTION TRANSMITTING TRANSDUCERS: POLARISATION. Many transmitters operate on the lines described above. Some have a permanent magnetic field induced into them, either by a permanent magnet or by a steady d.c. current which flows through the windings; they are then said to be polarised. A polarised transducer will convert electrical energy into sound energy more efficiently than an unpolarised one. Polarisation generally alters the correct relationship between the natural frequency of the nickel stack and the frequency of the applied current.

(*b*) MAGNETO STRICTION RECEIVING TRANSDUCERS; FLASHING. If the receiver is to convert the extremely weak sound waves which strike it into electrical energy with any sort of efficiency, it must be made very sensitive indeed. Its sensitivity is greatly increased if it posseses a small amount of residual magnetism. This magnetism is produced by passing a large but short d.c. pulse through the windings of the transducer, before it is put into use, and thereafter at about three-monthly intervals. The operation is known as 'flashing the receiver', and it must always be carried out before a set is put into service. When flashing a receiver, it is wise to do it two or three times at least, since the first pulse may by chance merely neutralise the residual magnetism already in the stack.

If an echo sounder produces a very weak signal for no apparent reason, it may well be that the receiver needs flashing.

(ii) Piezo electric transducers. Fig. 3–10 shows a typical piezo electric transducer, mounted in the bottom of a vessel. To work properly it must be fed with a high alternating voltage; it does not need a great deal of current. It is a very efficient converter of electrical energy into sound energy, particularly at high frequencies, but it will not handle so much power as a magneto striction transducer. For this reason it must be fitted in direct contact with the sea. Although it is recessed into the hull, it is outside it and cannot be replaced whilst the vessel is waterborne.

The transducer consists of two steel discs *A* and *B*, between which is cemented a quartz element made up of a mosaic of specially cut quartz crystals. All three layers are very firmly cemented together, and can only vibrate as one unit. If a potential difference is applied between discs *A* and *B*, the quartz will decrease in thickness; reversal of the potential difference will cause it to increase in thickness; on the removal of the potential it will return to its original dimensions. In practice a high alternating voltage is applied between *A* and *B* (*B* is usually earthed); this causes the complete unit to oscillate in sympathy. The oscillations, and hence the sound waves, which are transmitted as shown in the figure, will have a maximum amplitude if the natural frequency of the transducer matches that of the applied alternating voltage.

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* For a plate to transmit all the sound energy that strikes it, its thickness must either be zero or half a wavelength. The echo sounding wavelength in steel for a frequency of 14 kc/s is about 14 inches. Therefore the bottom-plate should be about seven inches thick for most efficient transmission.

PIEZO-ELECTRIC TRANSDUCER ASSEMBLY

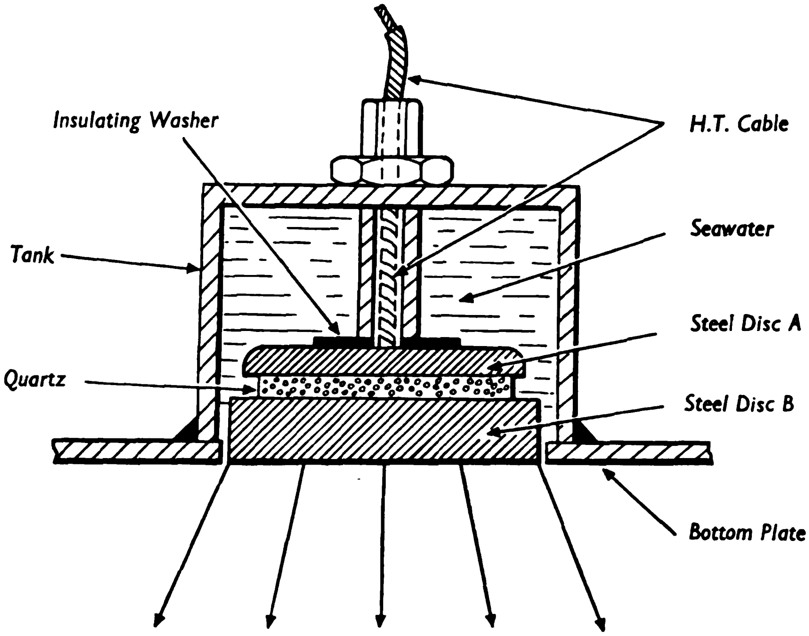

Fig. 3–10

Sound waves returning from the sea bed impinge on disc *B*, and cause the unit to oscillate. This physical oscillation alternately compresses and stretches the quartz, which then creates a very small alternating voltage between *A* and *B*. This process is the exact reverse of that described above.

Piezo electric transmitting and receiving transducers are completely interchangeable. They do not need a polarising current or flashing. In many installations one transducer is made to perform both the functions of transmission and reception.

Several other materials, besides quartz, will behave as piezo electric oscillators. Some of them are man-made plastics which can be moulded into special shapes which will concentrate the sound waves into a beam of any desired width.

f. The receiving amplifier and associated circuits

The design of receiving amplifiers provides almost endless scope for the electronic engineer. No two amplifiers are exactly alike. However, if an amplifier is to meet the needs of the hydrographic surveyor it must have the following attributes:

(1) It must be possible to vary the overall gain easily and whilst the set is in use. This adjustment is the same as the volume control on a radio set.

(2) It must be possible to prevent the relatively very high powered transmission pulse from making the echo trace completely black for some width, as this may mask a weaker echo signal that would otherwise show up on the trace. This end is achieved by applying initial suppression.

The description that follows is greatly simplified for the sake of clarity; however, if the principles set out are grasped they may be applied to the far more complicated equipment which will be met with in practice.

(i) The pre-amplifier; gain control; initial suppression. Fig. 3–11 shows the circuit diagram of a very simple pre-amplifier. It is fed with a minute electrical signal from the receiving transducer and produces a few volts output. As shown, it is capable of marking low voltage damp iodised paper; however, if high voltage dry papers are used as a recording medium, an additional power amplifier must be used. Since almost all modern sets use high voltage dry paper, the term pre-amplifier is coming into use as a description for what should more properly be called a simple amplifier.

Referring to Fig. 3–11, suppose that the receiving transducer is being energised by a pulse of sound returning from the sea bed. The magneto strictive or piezo electric effect will cause a minute a.c. current to flow in the primary (left hand) winding of transformer *TR1*. This will be transferred to the secondary winding of this transformer and will flow in the circuit containing this winding and the condenser *C1*. In simple terms, *C1* will be charged and discharged in step with the original signal. For an efficient transfer of energy in the transformer the secondary circuit must be tuned to the same frequency as the primary. Condenser *C1* is therefore made variable; it is known as the tuning condenser. Unless it is properly tuned an echo set will give poor results; its adjustment is simple and not very critical.

Now, the lower side of *C1* is connected (via *R1*) to earth and the cathode of valve *V1*; its upper side is connected to the grid of *V1*. Therefore any voltage changes across *C1* will appear between the grid and cathode of the valve, and will alter the current flowing between the cathode and anode of this valve. At the point *x* there will be an alternating voltage, similar to that across *C1* but greatly amplified. This voltage causes an alternating current to flow through the coupling condenser and *R3*, to the H.T. negative line, which is also connected to the cathode of *V2*. Since there must be a voltage drop across *R3*, the sliding contact on it can be made to select any proportion of the voltage output of *V1*, and apply it to the grid of *V2*; *R3* is the gain-control potentiometer. It is usually possible to adjust it whilst the set is running.

The signal passes through valve *V2* in the same manner, and appears at the point *y* as a few volts a.c.; the current available at this point will usually be quite small, perhaps in the region of a fraction of one ampere. However, provided it is first rectified, this is enough to mark damp iodised paper.

If the amplifier were not fitted with initial suppression, the relatively powerful transmission pulse and its reverberations would swamp the first-stage valve *V1* and make it insensitive to returning echoes for some time. What is needed is a device which greatly reduces the sensitivity of *V1* just before transmission, and then returns its sensitivity to normal in a short period of time. The initial suppression circuits do this in the following way:

A short time before transmission takes place the insert on the drum on the stylus spindle in the recorder completes the connection between the two brushes, and connects the positive end of the suppression bias battery to the H.T. negative line, and hence to the cathode of *V1*. Condenser *C2* will immediately charge up to a voltage of anything up to six volts, depending on the setting of the potentiometer *R2*. The point *a* will be at a negative potential relative to the cathode of *V1*; so also will the grid of *V1*, since it is connected to *a* through the secondary winding of *TR1*. The valve will therefore be biased off just before transmission takes place, and will be very insensitive; its actual sensitivity during this period can be controlled by adjusting *R2*, which is generally known as the voltage control potentiometer. An instant before transmission takes place the brass insert on the drum on the stylus spindle breaks the connection between the suppression bias battery and the H.T. negative line. The charge on *C2* then leaks away through the variable potentiometer *R1*; the voltage at point *a* increases, and the valve regains its full sensitivity. The time taken for this to

SIMPLE ECHO-SOUNDING AMPLIFIER CIRCUIT

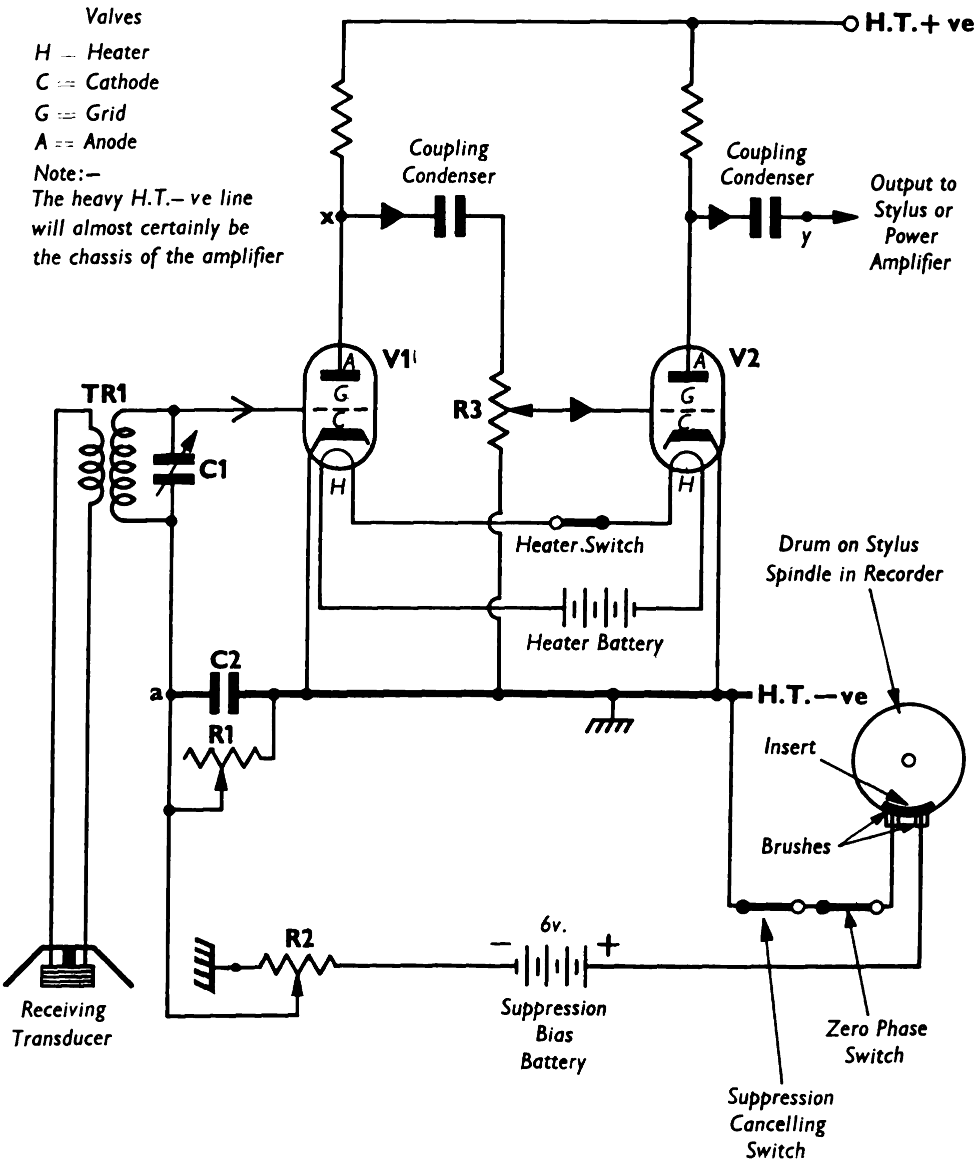

Fig. 3–11

happen depends on the setting of *R1*, which is known as the decay control potentiometer.

In many sets initial supression is only applied when the zero phase is in use; in some it is possible to cancel it at will. The zero phase and suppression cancelling switches in the diagram perform these functions.

Both the initial suppression controls are preset. An endless variety of settings is possible. The best is probably that which almost suppresses the transmission line completely, and returns the amplifier to its full sensitivity as soon as possible. This setting will generally allow the transmission reverberations to show up as fairly light grey or brown marks on the trace; they will certainly not prevent an echo from being detected through them. If in doubt it is always best to start with too little suppression, rather than too much, and a short decay period.

There is no reason why these controls should not be adjusted in the field as necessary to suit particular conditions. However, they are capable of altering the apparent depth quite appreciably in certain circumstances, and care and common sense must be applied to their use.

(ii) The use and abuse of initial suppression and gain. Used properly, initial suppression greatly enhances the performance of the average echo sounder in fairly shallow water. When used improperly it may well lead to the incorrect depths being recorded.

Suppose the initial suppression is set to all but suppress the transmission line, and that the amplifier sensitivity does not return to its full normal value until the stylus has reached a depth of 40 feet; all bottom echoes from less than 40 feet will be attenuated, the more so as the depth becomes less. In areas of hard bottom where there is plenty of echo power to spare this will probably not matter. But if, for instance, the bottom is soft mud with a very ill-defined boundary between water and sea bed, the effect of having too long a decay period may well be to obliterate the leading edge of the echo and make the apparent depth greater than it ought to be. If this trouble is suspected, use of the suppression cancelling switch will generally be helpful; if the suppressed and unsuppressed apparent depth is the same, all is well. If it is not, common sense and judgement must be used. In many areas of soft bottom there is no real way of deciding where the water stops and the bottom begins. The boundary layer may well be two or three feet thick and have a consistency varying from that of pea soup to thick porridge.

When an echo sounder is calibrated, perhaps with a bar check, the object whose depth is measured will almost certainly be hard or firm, and will give a relatively strong return echo. If the sea bed is soft, or for some other reason returns an echo less robust than that received from the bar check, badly selected initial suppression settings may well lead to incorrect depths being recorded. Once more they are almost certain to be greater than they ought to be.

If, when sounding in deep water, an echo 'once round the clock' returns during the zero phase period, it will be affected by initial suppression as it approaches the transmission line. In some cases it may be attentuated so much that it cannot mark the trace. Use of the suppression cancelling switch will not generally help here, since it will cause the transmission and its associated reverberations to darken the trace over an appreciable depth. The best plan is probably to set the initial suppression so that the transmission line is thin and the reverberations are of a light to medium toned colour; the echo will then probably show through the reverberations.

Errors in recorded depth can be caused by misuse of the gain control. As the gain is reduced, weak bottom echoes will be lost and stronger ones may well appear to be deeper than they really are. The prudent surveyor will always use as much gain as possible, provided the trace is clear, and he will not alter the gain setting between calibrations of the equipment.

(iii) The power amplifier. Power amplifiers are necessary when dry recording paper is being used, to produce the power necessary to mark it. They are fed with the output from the pre-amplifier, and boost this to a voltage of anything between 75 and 200 volts, depending on the design of the equipment; their output current is much greater than that of the average pre-amplifier. Power amplifiers often consist of two valves working in 'push-pull'; the design and operation of the circuit follows normal radio practice. Their output is not usually rectified before being applied to the stylus.

g. The recorder and associated equipment

Fig. 3–12 shows a typical recorder in diagrammatic form. Fig. 3–13 illustrates a modern recorder used in the surveying service of the Royal Navy. The design of recorders offers endless scope to the manufacturer, and no two designs will have the same features. In what follows, basic principles and desirable qualities will be stressed in preference to detail, which can be obtained from the maker's handbooks.

The machines illustrated in Fig. 3–12 and 3–13 are capable of registering depths to the nearest half fathom (or foot), with an accuracy of about one part in two hundred. The precision depth recorder, which may be used for rigorous deep water sounding, is described in Section **36a** of this chapter.

(i) The recorder motor and governor; speed control and measurement; hunting. Recorder motors may be high or low voltage d.c. operated, or driven by alternating current, in which case they are almost always synchronous. Direct current motors are generally fitted with centrifugal governors; their speed can be altered over a small range by a speed control knob. Synchronous motors lock themselves to the frequency of the a.c. supply; this frequency, and hence the motor speed, can usually be varied over a small range by a speed control knob fitted on the rotary converter which supplies the power. Whatever the source or type of supply, or type of motor, this facility to vary the speed at will is essential, since upon it depends the surveyor's ability to match the speed of rotation of the stylus to the speed of sound in water. (*See* Section **2c(i)** of this chapter.)

A good recorder motor and governor will maintain a steady speed once it has been set. Not all motors and governors are good, and the surveyor must be constantly alert to detect and correct bad governing. Dirty brushes, sparking, weak springs and fluctuations in the voltage of the ship's mains can all cause speed variations. Some motors hunt quite appreciably about a mean speed, which may be correct. The effect of this fault is to produce a rippled echo trace. The transmission line will be firm and sharp, but echoes will be rippled even over a flat bottom. The ripples will probably be more pronounced in deep water. It may just be possible to detect a definite periodic fluctuation in the echo, particularly if a bar check is being used. If variable-speed paper drive is fitted, a sure test is to switch to the fastest paper speed. Each individual trace of the stylus pen should be visible, and hunting will show up as a definite sine wave in the shape of the bottom trace; its period will probably be a second or two. The fault lies in the governing mechanism, and much patience and ingenuity is required at times to reduce it to an acceptable amount.

The modern trend is to provide electronic or electromechanical devices to measure and indicate motor speed. The vibrating reed tachometer is often employed. Whilst these devices are useful, they should not be relied upon implicitly. Tachometers can give false readings; reeds can be stimulated into vibration by sources of energy not in any way connected with the echo sounding recorder they are meant to be monitoring.

Every recorder motor is connected to a stylus, or moving arm of some sort, by a train of solid gears, and the motor speed is bound to be a fixed function of the stylus speed. The most reliable form of speed measurement is therefore to compare the rotation of the stylus with time as indicated by a well adjusted stopwatch.

In some recorders interval marks appear on the record every few minutes; these marks are triggered by the recorder motor, and the time interval between their appearances is a simple function of the motor speed.

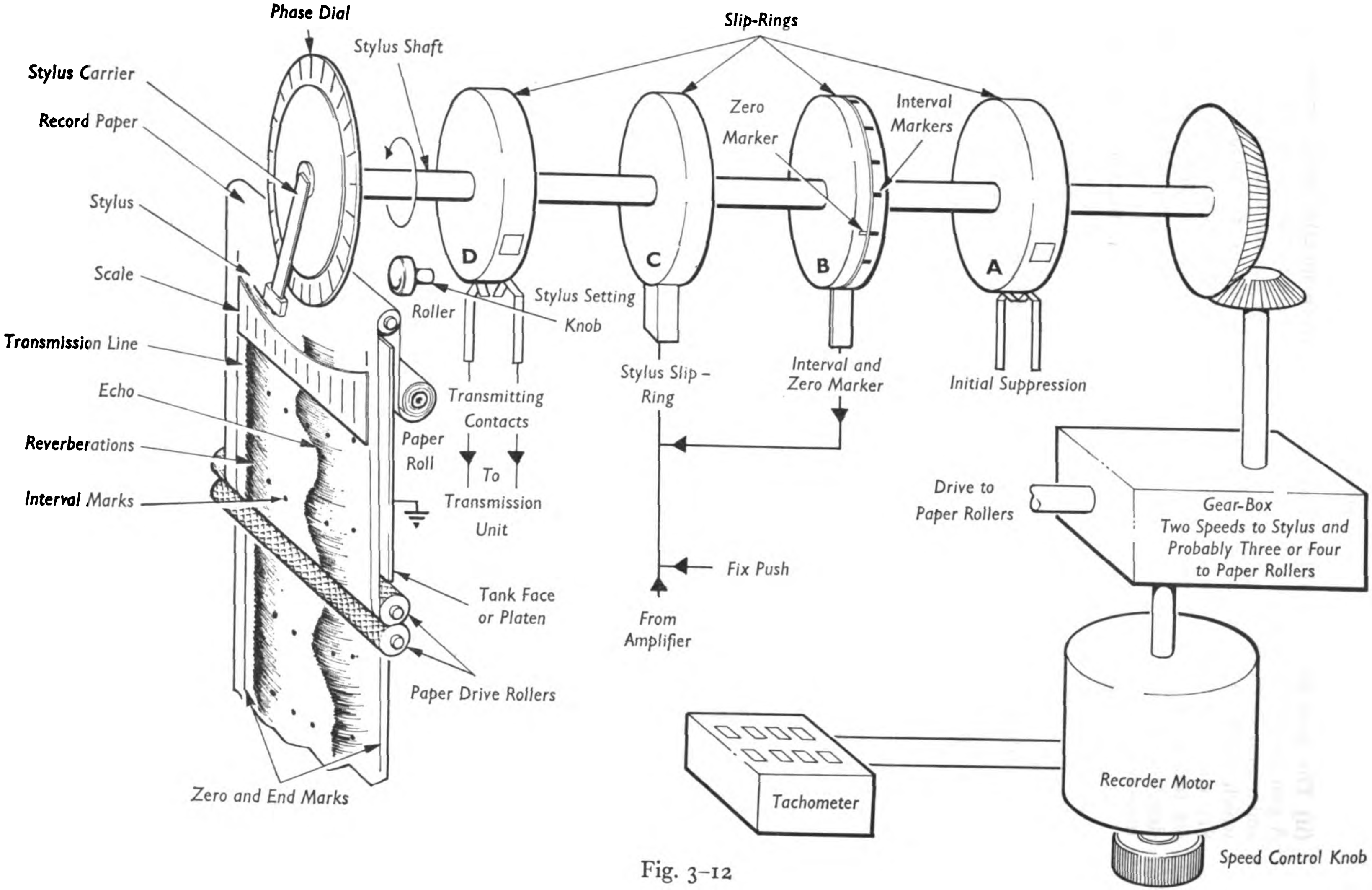
Phase Dial
Stylus Shaft
Slip-Rings
Stylus Carrier
Record Paper
Stylus
Scale
Transmission Line
Echo
Reverberations
Interval Marks
Zero and End Marks
Zero
Marker
Interval
Markers
D
C
B
A
Roller
Stylus Setting
Knob
Transmitting
Contacts
To
Transmission
Unit
Paper
Roll
Tank Face
or Platen
Paper Drive Rollers
Stylus Slip –
Ring
Interval and
Zero Marker
Initial Suppression
Fix Push
From
Amplifier
Drive to
Paper Rollers
Gear-Box
Two Speeds to Stylus and
Probably Three or Four
to Paper Rollers
Tachometer
Recorder Motor
Speed Control Knob

Fig. 3–12

(ii) The gear box; variable stylus and paper drive speeds; backlash; grass. A gear box is necessary to reduce the speed of the motor to that of the stylus shaft, and to provide the drive for the paper drive rollers. Most gear boxes have a mechanism which enables the surveyor to select one of two speeds for the stylus shaft; the first corresponds to the measurement of depths in feet or metres, and the second is six times (for fathoms) or 10 times (for metres × 10) slower. British gear boxes designed for deep sea work usually provide output speeds corresponding to depths measured in fathoms and fathoms × 10.

All gear boxes produce a drive for the paper drive rollers, so that the record paper is drawn across the tank face at a steady speed. Some have a selective device, which will produce three or four paper speeds, varying in steps from a fraction of an inch to several inches per minute. This facility is a great asset. The slower paper speeds prevent the waste of paper in small scale work, and the faster speeds are most useful when the scale of the survey is large. The fastest speed of all is particularly useful in the diagnosis of faults, for it enables each individual transmission and echo trace to be examined separately.

The endemic disease of gear boxes is backlash. Boxes which are apparently quite serviceable suffer from it, and its effect can be most insiduous and annoying. If the load on the gear box were even, a little backlash would not matter. However, once per revolution of the stylus arm, various contacts are operated; this throws a slight but nevertheless very measurable extra load on the gear box. If backlash is present the stylus arm may bounce slightly as the contacts make or break. The result can be transmission marks, which move about on the trace in a random manner, over perhaps a foot, and an echo that is 'furry' or 'grassy'. If there is backlash in the gear box worm drive, displacement of the echo may take place at relatively long intervals, with the result that a correctly adjusted echo suddenly reads a foot or two deep or shallow. Diagnosis is made much easier if the fastest paper speed is used. Backlash usually means that the gear wheels are worn, and replacement of the gear box with a good one is the only certain cure. Sometimes it is very difficult to determine whether the gear box or transmitting contacts are faulty (*see* (vi) below).

(iii) The initial suppression slip ring and contacts. In Fig. 3–12 the initial suppression slip ring *A* is made of insulating material, with a small insert of metal. It is generally firmly attached to the stylus spindle. Two contacts or brushes bear against this ring. Once per revolution, just before transmission takes place, the contacts are short-circuited by the metal insert, and the initial suppression circuit is completed. They are open circuited again an instant before transmission takes place.* In most recorders the relative positions of the contacts and the metal insert can be adjusted over a small range. The adjustment is simple, but it is very critical, and great care is necessary.

(iv) The interval, zero and end markers. The interval, zero and end marker generators are very often combined in the same slip ring and brush assembly. In Fig. 3–12 slip-ring *B* is split into two halves, which revolve together, but are separated electrically.

The left-hand half has two small brass strips let into its surface, which are electrically energised. One of these strips will pass under the brush as the stylus passes the zero mark on the scale, and the other as the stylus reaches the right-hand (deep) limit of the scale. When this happens current will flow through the record paper, via the stylus slip-ring and the stylus, and a mark will be made on the paper corresponding to the zero and end marks on the scale. A slight adjustment between the relative positions of the slip ring and brush can be made with most recorders; it is simple to make

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* The circuit is broken just before, and not just after transmission takes place as it is then easier to make adjustments to the initial suppression.

A MODERN DRY-PAPER RECORDER

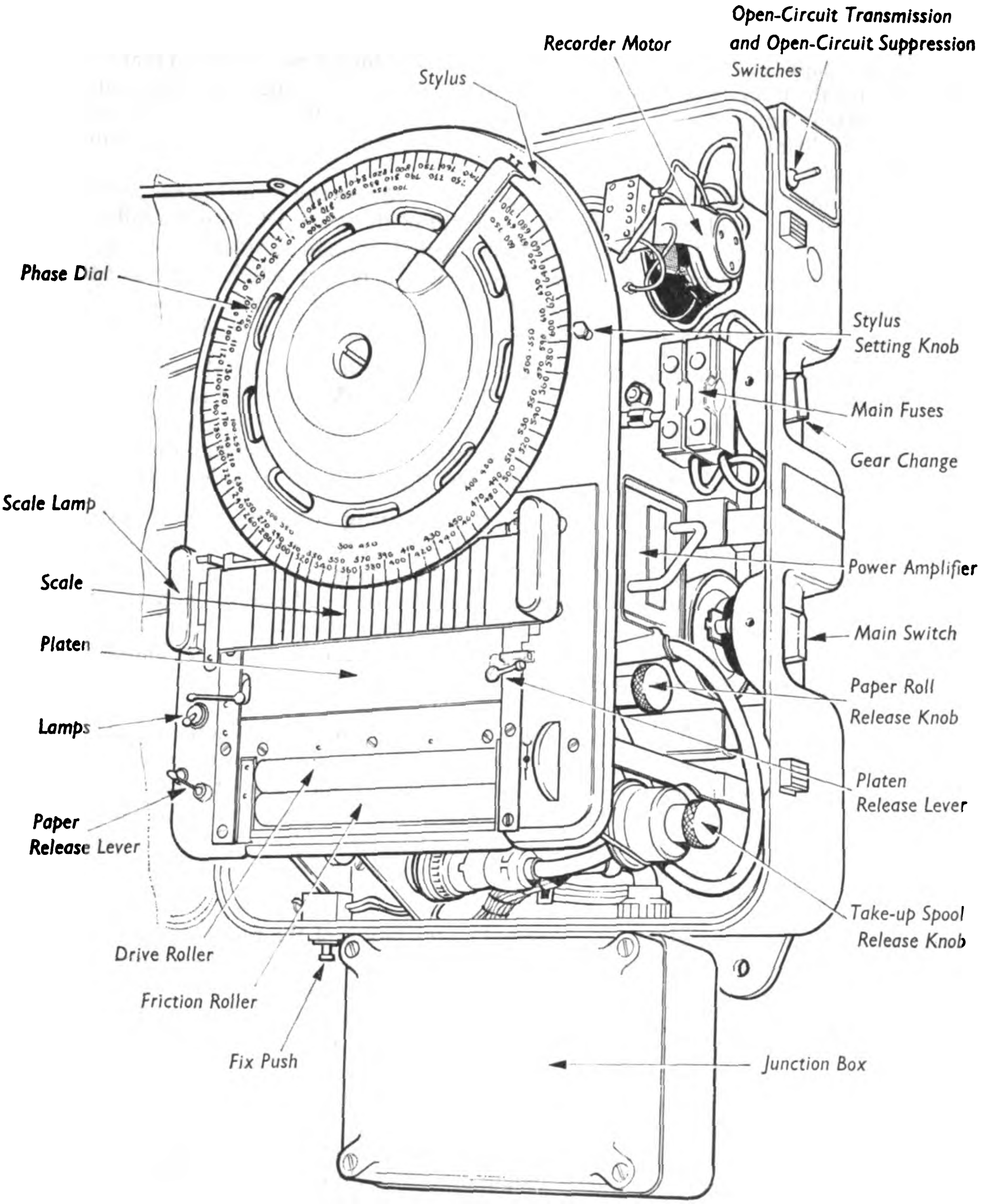


Fig. 3–13

but very critical. End markers are not always provided, but they are a great asset, as with the zero markers they provide a safeguard against undetected distortion of the paper after the record has been made.

The right-hand half of the same slip ring contains several interval marking strips, which might well be placed the equivalent of 10 feet of depth apart. These strips are energised for a few seconds once every two or three minutes by a rotary switch driven off the recorder motor. When this happens small rectangular marks will appear on the record paper at 10-foot intervals. The adjustment for the zero and end markers serves also for the interval markers. With the advent of dry recording paper, interval markers are often omitted from recorders; they are very necessary to guard against the uneven shrinkage of the paper, which is so common when damp starch iodide papers are used.

In some recorders zero and end marks are made on the record paper by the direct action of two small springs fitted at each end of the scale, which press lightly on the paper, passing an electric current. This method, though simpler and in many ways more attractive than the one described above (it is very much easier to adjust the marker settings), is suited to damp rather than dry paper recorders, since in the latter much higher voltages and currents are needed to mark the record.

(v) The stylus slip ring; the fix push. All signals destined for the stylus must pass through the stylus brush and slip ring. This is a simple ring and brush assembly, and should give no trouble provided it is not abused. When the fix push, either on the recorder or on a wandering lead, is pressed, a current passes through the record paper via the stylus slip ring and stylus, and a continuous mark is made on the paper.

(vi) The transmission slip ring and transmitting contacts. Fig. 3–12 shows one pair of transmitting contacts, which are bridged once every revolution of the stylus shaft by the metal insert in slip ring *D*. Practical arrangements will be far more complex; there will be two sets of contacts, one for feet and one for fathoms, fed by a common slip ring, probably operated by two cams, and switched in and out by microswitches. Individual arrangements are described in the makers' handbooks. Modern recorders are quite frequently fitted with motor cycle magneto make-and-break units, which serve as transmission contacts.

Sparking, pitting and dirt are the chief enemies of transmission contacts. If they are badly looked after or adjusted incorrectly they can bounce as they make or break; this can lead to the generation of a double transmission. If this trouble is suspected, the fastest paper speed can be of great use in diagnosis, since it is unlikely that the bounce will be regular, and the irregularities will show up on the trace. Sometimes it is very difficult to determine whether the transmission contacts or the gear box are faulty (*see* **(ii)** above).

(vii) The phase dial; phase error. The operation of the phase dial has been discussed in Section 2c of this chapter. As was stated there, it can be revolved in steps which are usually simple fractions of 360°. It is held in these various positions by a mechanical catch. If, due to defects in manufacture, these steps are not all equal, phase error will be present. On the record, phase error appears as a discrepancy in depth when the position of the phase dial is altered by one step. Nothing can be done in the field to eliminate it, but it can very easily be allowed for. All recorders should be checked for phase error before they are put into use.

In practice, either the transmitting contacts or the cams operating them, will be fitted to the phase dial. There should be some means of adjustment so that the transmission line can be set to any reasonable depth.

(viii) The stylus carrier and stylus; the stylus setting knob. The stylus carrier is rigidly attached to the end of the stylus shaft. It carries the stylus, which in dry paper sets is a short length of tungsten wire, part of which is coiled in the form of a spring. Damp paper recorders usually have a more robust stylus, which is pivoted on the end of the stylus carrier and is lightly spring loaded.

It is essential that the point of the stylus, as it traverses the record paper, should not move relative to the rotating part of the transmission contact assembly, and that its radial distance from the centre of the stylus shaft should be correct and never vary. Therefore the stylus carrier itself must be rigid; the stylus must be very firmly attached to its end; any spring loading arrangements must have a constant effect on the stylus as it crosses the paper; and the stylus itself must remain the same length.

Most of these requirements are taken care of by the maker when he designs the set. On damp paper recorders the stylus is not likely to give much trouble, provided it will mark the paper at all. However, the comparatively heavy current passing through a dry paper stylus burns away the tip of the wire fairly quickly, and regular checks must be made if errors are to be avoided. In some sets the stylus wire is adjusted in its holder until its point just touches the stylus setting knob illustrated in Fig. 3–12; it will be wise to check that it is still doing so every hour or so that the recorder is in use.

(ix) Echo sounding record paper. In the past, most recorders were designed to use rolls of damp paper impregnated with starch and potassium iodide, which left a brown stain when a current passed through them.

Although damp paper works very well, it has certain disadvantages from the surveyor's point of view:

(*a*) It usually shrinks considerably, and perhaps unevenly, on drying.
(*b*) The image fades with time, and vanishes in an hour or two if a newly used roll is exposed to sunlight.
(*c*) The quality varies from roll to roll.

It has been replaced almost exclusively in modern recorders by dry paper.

Dry recording paper usually consists of two or three layers of specially prepared white and black paper, laminated together so that the black layer is either on the back or in the middle. The recording current burns off the front layer of white material, and the black shows through to form the sounding record. Comparatively high voltages and currents are needed; the three layer variety of paper (white on both sides) needs more than the two layer variety (black on the back); it is less sensitive to weak echoes but is much cleaner to handle. Dry paper does not shrink or fade, and is not affected by sunlight. It can be written on with an ordinary pencil. In some circumstances it may not record quite such fine detail as the damp paper which it has replaced, but for general surveying use it is far superior.

(x) The tank face or platen. The tank face is a highly polished metal plate, which both supports the recording paper and provides the earthed end of the electrical marking circuit. Although the paper moves, the tank face does not, and the stylus always traverses it along the same circular arc. The marking current slowly but surely destroys the surface along this arc, and after a time pitting will occur, a groove may well be formed, and the electrical connection between the tank face and the paper will be impaired. A pitted or badly worn tank face will reduce the density of the trace, and may, if it is bad, cause spurious marks to appear on it. It is therefore important to ensure that the metal surface is always in good condition. In most recorders the top section of the tank face, where all the wear takes place, can be removed separately from the main plate, for repair or replacement. This section very often is nickel plated and should always, when new, be highly polished, with no signs of scoring or pitting.

Tank faces in dry paper recorders wear away quite quickly, owing to the high voltages and currents employed. In damp paper sets they last much longer, but generally accumulate a layer of pulped paper along the arc traversed by the stylus, which reduces the quality of the record very appreciably. It is quite easy to clean this layer off from time to time with a moistened thumb nail. On no account should any metal object be used.

Whenever a damp paper recorder is not in use, the paper should be removed from the tank face, as otherwise the chemicals in it will attack the surface of the metal, particularly where pitting or scoring is already present. Dry paper may be left permanently over the tank face, since it does not attack the surface.

3. Echo Sounders; Corrections

A well adjusted echo sounder must be properly calibrated before the apparent depths recorded by it will approximate to true depths. To obtain true depth, various corrections must generally be applied to apparent depth. Some of these corrections can be calculated; others can only be estimated. The methods and processes described in this section are designed to simplify the production of accurate results as much as possible.

a. The points of transmission and reception; the transmission line: index error

It is very difficult at any time, and virtually impossible in a ship at sea, to determine accurately the points of transmission and reception. When the transmitting transducer transmits a pulse of sound energy, this energy will reach the receiver via two paths at least; some of it will travel very fast through the ship's bottom plates, and some will travel more slowly along the direct water path immediately below the ship. On arrival at the receiving transducer the pulse will initiate the formation of the transmission line on the recorder paper, which should appear at about the depth of the transducers. However, it is important to realise that there cannot be a fixed relationship between the draught of the transducers and the depth at which the transmission line appears on the record paper. In some installations it may well happen that, owing to bad screening in the feeder cables, the transmission pulse enters the receiver circuits before either the transmitting or receiving transducers are fully energised; this will cause it to appear on the trace earlier than would otherwise be the case.

The bar check procedure described in Section **4d** below enables the surveyor to set the instant of transmission correctly, and determine the index error of the equipment, without referring to the transmission line on the recorder trace, or knowing the exact draught of the transducers. When, and only when, the instant of transmission has been correctly set, the apparent depth of the transmission line may be read off the trace and used to ensure that the transmission does not wander whilst the set is in use.

If the instant of transmission must be set, and a bar check or other calibration procedure cannot be carried out, the best course is probably to set the transmission line on the recorder to the depth of the transducers below the water line. Such a setting will generally be adequate for navigational purposes, but the surveyor should remember that it may be in error by anything up to about a foot. Note that transducers, particularly those operating by magneto striction, are not always fitted close to the bottom of the ship.

It should be obvious from the foregoing remarks that the transmission line should never be set to the *ship's* draught. If, as is generally the case, the ship's draught is greater than the draught of the transducers, such a practice will lead to apparent depths being greater than they ought to be.

b. Separation error

Fig. 3–14 shows two transducers fitted in the bottom of a ship, their distance apart, or separation, being s units. The transducers are d units above a flat sea bed, whose depth below the waterline is $d + h$. It follows that the draught of the transducers is h; this will almost certainly not be the draught of the vessel concerned.

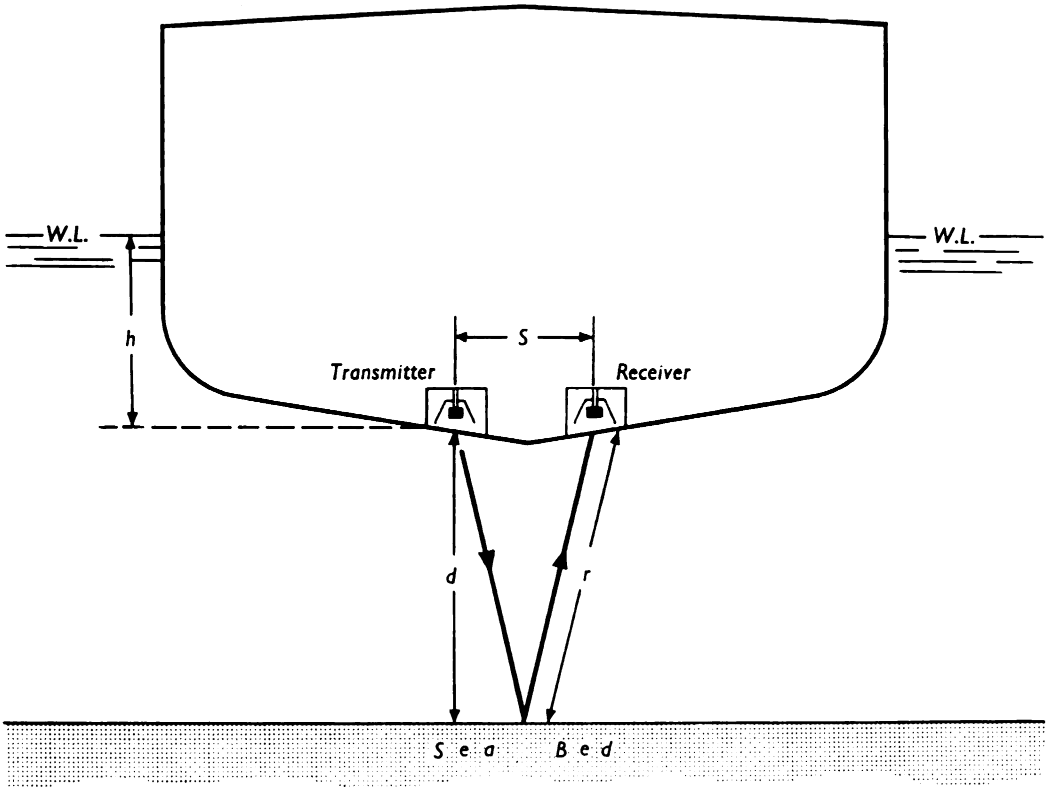


Fig. 3–14

The true depth at the point illustrated is

$$d + h,$$

but the echo sounder, owing to the fact that the echo must travel along the arrowed path, will indicate a depth of

$$r + h.$$

This indicated depth will always be greater than it ought to be, and the separation error will equal

$$(r + h) - (d + h) = r - d.$$

It may be expressed more conveniently in the form:

Separation error (always subtractive to apparent depth) $= r - \sqrt{r^2 - \frac{1}{4}s^2}$

where r = Apparent depth below transducers (*not* the waterline)

and s = Distance apart of the transducers.

Separation error increases as the depth decreases; it can never exceed half the separation of the transducers. It is tabulated in the following table.

Provided the separation is not greater than six feet, values of separation error may be taken from the curves in Fig. 3–15. The use of the pecked parts of the curve should be avoided except in very special circumstances, for two reasons: firstly, the separation error changes very rapidly with change in apparent depth in this region of the graph;

SEPARATION ERROR

SEPARATION OF TRANSDUCERS IN FEET	APPARENT DEPTH BELOW TRANSDUCERS AND SEPARATION ERROR, IN FEET															
	1	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
1	0·14	0·06	0·03	0·02												
2	1·0	0·27	0·13	0·08	0·06	0·05	0·04	0·04	0·03	0·03						
3		0·68	0·29	0·19	0·14	0·11	0·10	0·08	0·07	0·06						
4		2·0	0·54	0·34	0·25	0·20	0·17	0·14	0·13	0·11	0·10	0·09	0·08	0·08	0·07	0·07
5			0·88	0·55	0·40	0·32	0·27	0·23	0·20	0·18						
6			1·3	0·80	0·58	0·46	0·38	0·33	0·28	0·25	0·23	0·21	0·19	0·17	0·16	0·15
7			2·1	1·1	0·81	0·63	0·53	0·45	0·39	0·34						
8			4·0	1·5	1·1	0·83	0·69	0·58	0·51	0·45	0·40	0·37	0·34	0·31	0·29	0·27
9				2·0	1·5	1·1	0·88	0·74	0·64	0·57						
10				2·7	1·8	1·3	1·1	0·92	0·80	0·71	0·64	0·58	0·53	0·49	0·45	0·42
11				3·6	2·2	1·6	1·3	1·1	0·98	0·86						
12				6·0	2·7	2·0	1·6	1·3	1·2	1·0	0·92	0·83	0·76	0·70	0·65	0·61
13					3·3	2·4	1·9	1·6	1·4	1·2						
14					4·1	2·9	2·2	1·9	1·6	1·4	1·3	1·1	1·0	0·96	0·89	0·83
15					5·2	3·4	2·6	2·2	1·9	1·6						
16					8·0	4·0	3·1	2·5	2·1	1·9	1·7	1·5	1·4	1·3	1·2	1·1

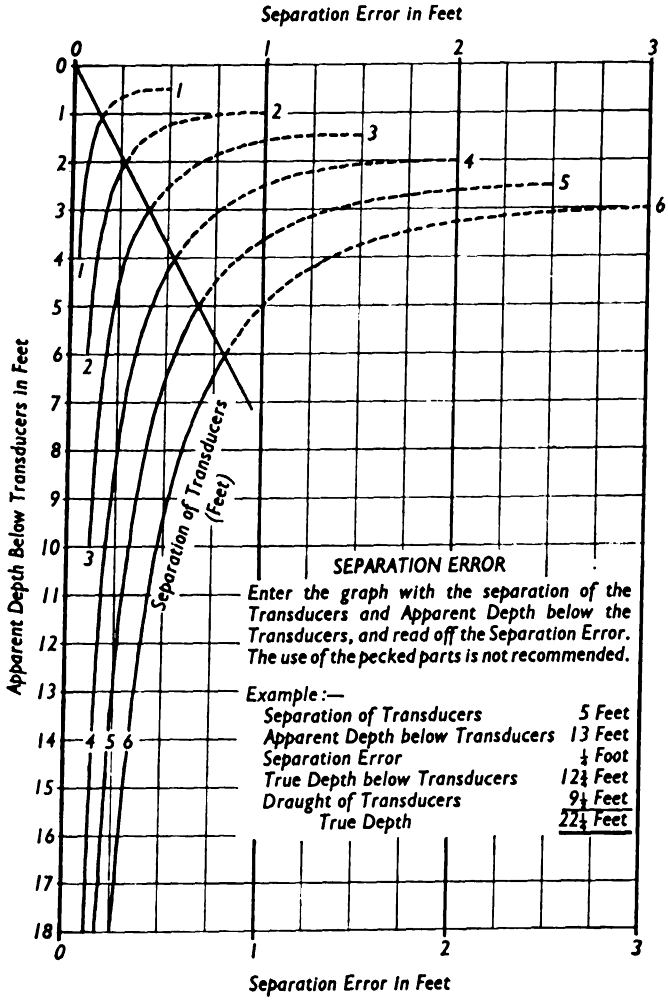
secondly, it will not always be possible to estimate the exact draught of the transducers (*h* in Fig. 3–14), and hence convert apparent depth below the water line accurately into apparent depth below the transducers. (Note that the depth of the transmission line will not help here, for the reasons stated in **a** above). Provided the apparent depth below transducers entered in the graph is within two feet of the correct value, and the pecked parts of the graph are not used, errors in the value of the separation error read off will not exceed two inches.

Separation error must always be allowed for when calibrating an echo sounder. If it is appreciable, it should be applied as a correction to soundings obtained in the field; the surveyor must decide each case on its merits. Dredging surveys may well demand the application of separation error corrections to a very high degree of accuracy.

Fig. 3–16 shows a graph connecting true depth and apparent depth. Graphs similar to it may be constructed for individual vessels, and used when calibrating and to correct shallow water soundings. The boat to which Fig. 3–16 relates has a maximum draught of three and a half feet; the draught of the transducers is two and a quarter feet, and their separation is two feet. Plotting figures for the graph are obtained in the following way:

A APPARENT DEPTH BELOW TRANSDUCERS	B APPARENT DEPTH BELOW WATER-LINE = A + 2¼ ft	C SEPARATION ERROR FROM COLUMN A AND FIG. 3–15	D TRUE DEPTH BELOW WATER-LINE = B – C
ft	*ft*	*ft*	*ft*
1	3¼	1·0	2·25
2	4¼	0·28	3·97
3	5¼	0·16	5·09
4	6¼	0·14	6·11

It can be seen from the graph that the boat will ground when the echo indicates the depth as being very nearly four feet. Had the boat's draught been two and a half feet, she would touch bottom in an apparent depth of very nearly three and a half feet.



SEPARATION ERROR

Enter the graph with the separation of the Transducers and Apparent Depth below the Transducers, and read off the Separation Error. The use of the pecked parts is not recommended.

Example:—

Separation of Transducers	*5 Feet*
Apparent Depth below Transducers	*13 Feet*
Separation Error	*¼ Foot*
True Depth below Transducers	*12¾ Feet*
Draught of Transducers	*9½ Feet*
True Depth	*22¼ Feet*

Fig. 3–15

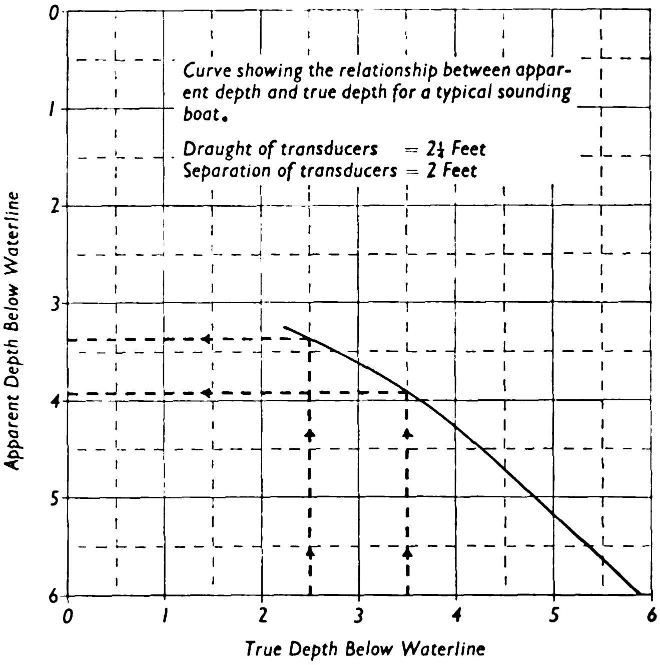


Fig. 3–16

c. Settlement and squat

Settlement causes the water level round a vessel under way to be lower than would otherwise be the case. It depends on the depth of water, the hull form and the speed of the vessel. It does not alter the draught of the vessel in any way. It will always cause echo sounding depths to be less than they ought to be.

So far as is known at the present time (1964), settlement is not appreciable unless the depth is less than about seven times the draught of the vessel; it increases as the depth becomes less, and with increase of speed. It has not been satisfactorily measured in the past.

Squat is the term used to denote a change in trim of a vessel under way, relative to her trim when stopped. It will normally cause the stern of a vessel to sit deeper in the water, by an amount that will vary with her length, hull form and speed. Depending on the siting of the echo sounding transducers, this may cause the recorded depth to be greater or less than it ought to be; if the transducers are fitted near the point of trim the effect of squat will probably be very slight. It has not been satisfactorily measured in the past.

The surveyor working in comparatively shallow waters will be interested in the combined effect of settlement and squat on his vessel at various speeds and in varying depths. It may be detected by the methods outlined below, and applied as a correction to apparent echo sounding depths.

(i) Measurement of settlement and squat in boats. Two boats are required, whose echo sounders have been carefully calibrated; in the procedure outlined below they are referred to as *A* and *B*. The measurement must be carried out over a fairly flat and smooth bottom, in calm conditions.

The procedure is as follows:

(*a*) Both boats stop close together and compare echo depths. Suppose that these agree exactly.

(*b*) *A* remains stopped. *B* moves away and then turns and passes close to *A* at sounding speed. Echo depths are compared as they pass.

(*c*) The settlement and squat of boat *B* at the speed and in the depth concerned will be the difference between the compared depths in (*b*) above.

The procedure may be repeated several times, and the roles of the boats may be interchanged. Speed and depth may be varied in order to obtain a complete picture.

(ii) Measurement of settlement and squat in a ship. In the procedure described below, a boat is used as the yardstick against which the settlement and squat of the ship is measured; the settlement and squat of the boat must be known (it will probably be very small indeed in depths greater than 20 feet or so, but *see* **(i)** above). Both echo sounders must be carefully calibrated beforehand.

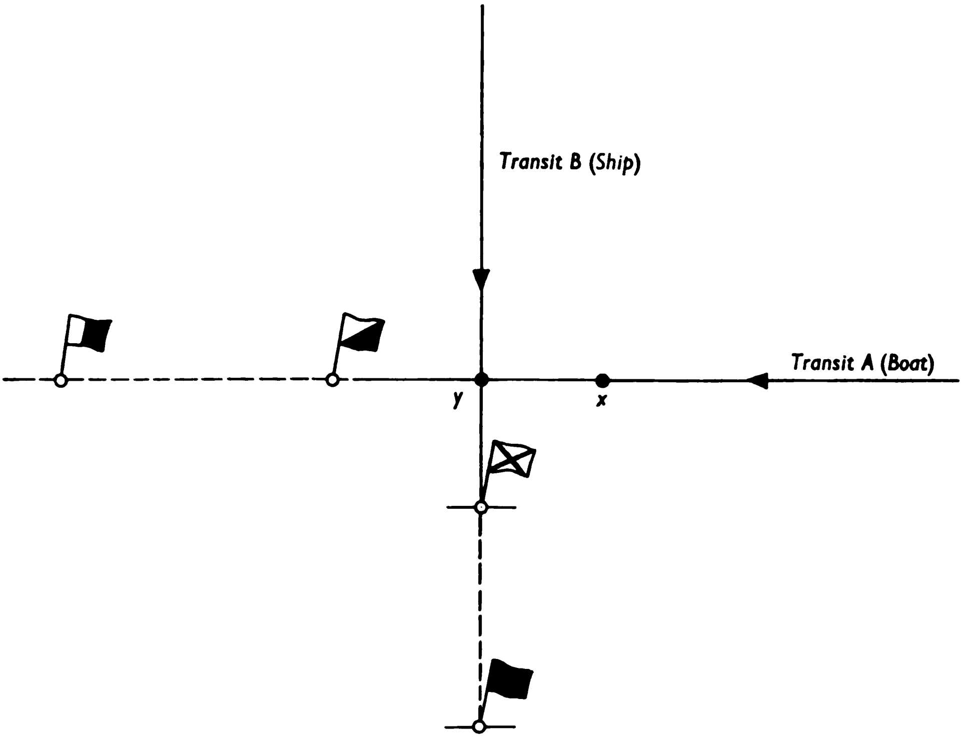


Fig. 3–17

Referring to Fig. 3–17, the procedure is as follows:

(*a*) The ship and boat stop close together and compare echo depths. Suppose these agree exactly.

(*b*) The ship then proceeds at sounding speed along the transit *B*, which may be natural or artificial, and in the direction of the arrow.

(*c*) The boat, which has been waiting on transit *A* at about the point *x*, crosses the ship's bows about half a cable ahead of her, taking great care to remain on the transit, and reads the echo depth at point *y* as transit *B* comes on.

(*d*) A few seconds later the ship reaches *y*, and the echo depth is read as transit *A* comes on.

(*e*) The depths in (*c*) and (*d*) should agree. If they do not, then provided the bottom is flat and smooth, and the sea is calm, the difference will be due to the settlement and squat of the ship and boat. Since that of the boat is known, the ship's may be calculated.

Several observations should be taken in order to reduce random errors. The procedure may be repeated in varying depths and at various speeds, in order to obtain a complete picture. Results may be plotted in the form of a graph equating speed, depth and the correction necessary to allow for settlement and squat.

4. Echo Sounders; Calibration

It was stated in Section **2a** of this chapter that depth is given by the expression

$$\text{Depth} = \tfrac{1}{2}vt$$

where v is the speed of sound in the water concerned and t is the time taken for the echo pulse to travel to the sea bed and back.

In Section 3 above, it has been seen that corrections for Index Error, Separation Error and Settlement and Squat must be made if the true depth is to be obtained. Methods are given there of calculating Separation Error and measuring the effect of Settlement and Squat.

Three variables remain:

(1) The index error.

(2) The speed of sound in water.

(3) The speed of rotation of the stylus arm, on which depends the measurement of the time interval t.

The index error is one of the corrections which must be applied to all apparent depths to reduce them to true depths.

The velocity of sound in water and the speed of rotation of the stylus arm are intimately connected. In theory, for the product $\frac{1}{2}vt$ to be correct, the velocity must be known accurately, and the measurement of t (in units of time) must be correct. In practice, the velocity is assumed to have a constant arbitrary value, the time interval t is converted into units of depth using this constant velocity (the spacing of the units on the engraved depth scale is arranged so that this is done automatically), and the speed of rotation of the stylus is then adjusted to compensate for the fact that the actual velocity may not equal the assumed velocity. For example, suppose that the actual velocity is greater than the assumed velocity; then in the formula

$$\text{Depth} = \tfrac{1}{2}vt$$

the value of v will be smaller than it ought to be; to compensate for this, t must be increased in proportion; this can be done by making the stylus arm rotate faster.

An echo sounder which is to be used in depths of less than about 100 fathoms may be calibrated by the bar check method without there being any need to know the speed of sound.

In what follows, the speed of sound in water, and the way in which it is connected with the speed of rotation of the stylus, will be discussed before some practical methods of calibration.

a. The speed of sound in water

Light travels through a medium in the form of transverse waves. The oscillations take place in a plane at right angles to the direction in which the energy is travelling. An ocean swell is an excellent example of a transverse wave; whilst the wave front moves horizontally, the individual particles of water move in a vertical plane.

Sound travels in the form of longitudinal waves; the oscillations take place in the same plane as that in which the energy is travelling, and small zones are alternately compressed and expanded. Imagine a long line of goods trucks standing stationary behind their engine on a level line; they are not fitted with brakes. The engine moves forward a few feet and stops. The movement will be transmitted down the line of trucks with the familiar clashing of buffers. If the truck axles are well greased, the movement may well be reflected back from the guard's van. The energy imparted by the engine to the leading truck travels down the line (and perhaps back again) in exactly the same way as a pulse of sound energy proceeding to the sea bed and back.

The speed of sound in any medium depends on the elasticity* and density of the medium. The greater the elasticity, the faster the speed; the greater the density the slower the speed. Elasticity usually has a greater effect than density. The elasticity and density of water both depend, in different ways, on temperature, pressure (or depth), and the salinity of the water. Fig. 3–18 shows, in diagrammatic form, how changes in these qualities affect the speed of sound. It can be seen that elasticity, and the speed of sound, increases with temperature up to about 40°C; increasing salinity and pressure also increase elasticity. Water has a maximum density at about 0–4°C; decreasing density either side of this maximum increases the speed of sound; increasing salinity and pressure both increase density, and therefore tend on this account to reduce the speed of sound.

Imagine a pulse of sound travelling vertically downwards through a column of water

SPEED OF SOUND IN WATER

Diagram Showing how Changes in Temperature, Salinity, and Pressure (or Depth) affect Elasticity and Density, and therefore the Speed of Sound

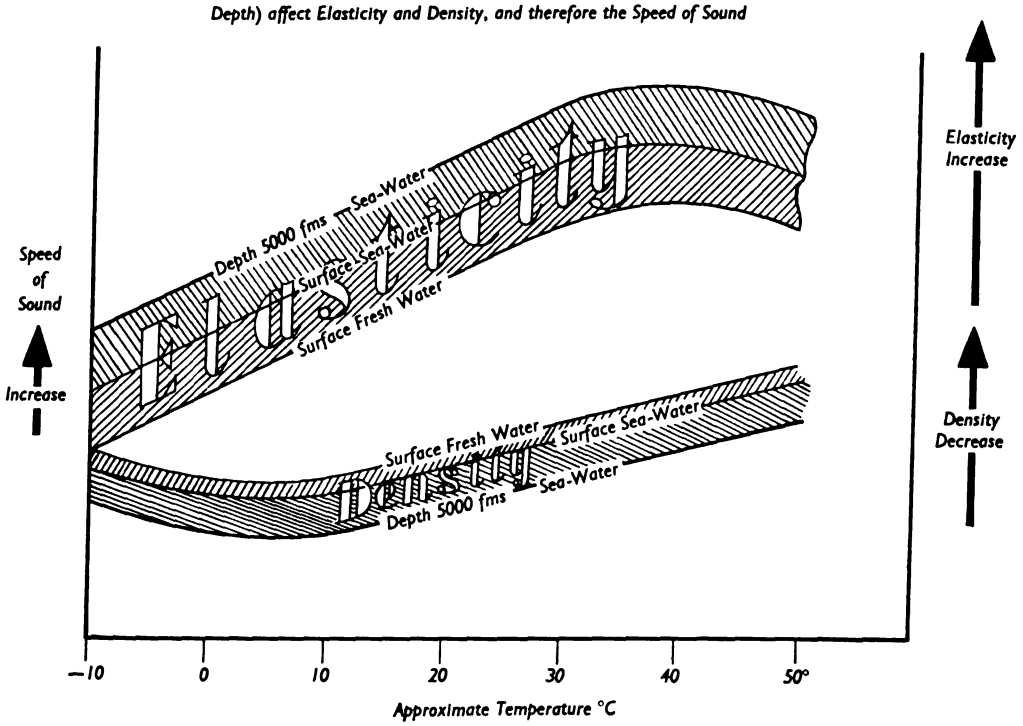


Fig. 3–18

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* The reciprocal of elasticity is compressibility; this term is often used in calculations concerning the speed of sound.

of constant salinity, and about 1,000 fathoms deep. Near the surface the temperature will be relatively high; pressure will be relatively low; from Fig. 3–18 the speed of sound will therefore be quite high. As it gets deeper the temperature will generally drop and pressure will increase; the net result of these changes is usually to reduce the speed of sound with depth, a minimum being reached at about the depth at which the temperature becomes stable. Below this level, increasing pressure, combined with a steady temperature, will cause the speed of sound to increase with depth. Salinity changes will, of course, complicate the pattern of change.

It can be seen that an echo pulse travelling to the bottom and back will move with a varying speed. The surveyor wishing to solve the equation

$$\text{Depth} = \tfrac{1}{2}vt$$

will be interested in the value of the average velocity v, unless, of course, he can calibrate his echo by the bar check or similar methods, which make this knowledge unnecessary.

There are two methods of obtaining the average velocity v:

(1) By direct measurements with a velocity meter, which can be lowered to the bottom.

(2) By indirect methods. If temperature, pressure and salinity are measured, velocity can be calculated.

Provided good instruments are used, method (1) is much better than method (2), since it measures the velocity directly. Both methods are time consuming.

Tables exist which tabulate the speed of sound in sea-water against temperature, pressure and salinity; others tabulate velocity against pressure (or depth) for different areas of the world. All these tables are based on comparatively few observations (in 1964), and may introduce errors. They should be used with caution. They are being amended and improved as knowledge increases.

b. Timing the stylus on an echo sounder; equivalent sounding velocities

The speed of rotation of the stylus may be measured in several ways. Some machines may be fitted with a mechanical tachometer, which indicates rotational speed directly; others may incorporate vibrating reeds; stroboscopic methods may be used in some cases. All these methods are subject to errors which may be unacceptable to the hydrographic surveyor. The surest way by which he can measure rotational speed is to observe the time taken for a whole number of stylus revolutions (the more the better) with a reliable stopwatch. For this purpose the fathoms setting will usually be most convenient.

When switched to fathoms, the stylus in a typical set might well take 43·9 seconds to make 20 revolutions. This rotational speed would correspond with a depth scale showing 900 fathoms per revolution of the stylus, and an assumed velocity of sound of 820 fms/sec. This assumed velocity of 820 fms/sec. is known as the equivalent sounding velocity for that particular set (900 fathoms = one revolution of the stylus) running at that particular speed (20 revolutions of the stylus in 43·9 seconds). In any set the depth scale, which fixes the number of fathoms in one revolution of the stylus, cannot be altered. However, the rotational speed of the stylus may be altered at will between certain limits, by adjusting the governor on the motor, and the equivalent sounding velocity will alter in step. If the equivalent sounding velocity of the machine agrees with the average speed of sound in the column of water beneath the vessel, depths read off the scale will be correct. If the equivalent velocity is greater than the actual velocity, depths read off the scale will be too great (the stylus will in fact be rotating faster than it should be); if the equivalent velocity is less than the actual velocity, depths read off the scale will be too small.

Figs. 3–19(a) and (b) show how equivalent sounding velocity is connected with stylus speed and the depth scale. The design of the depth scale will determine how many

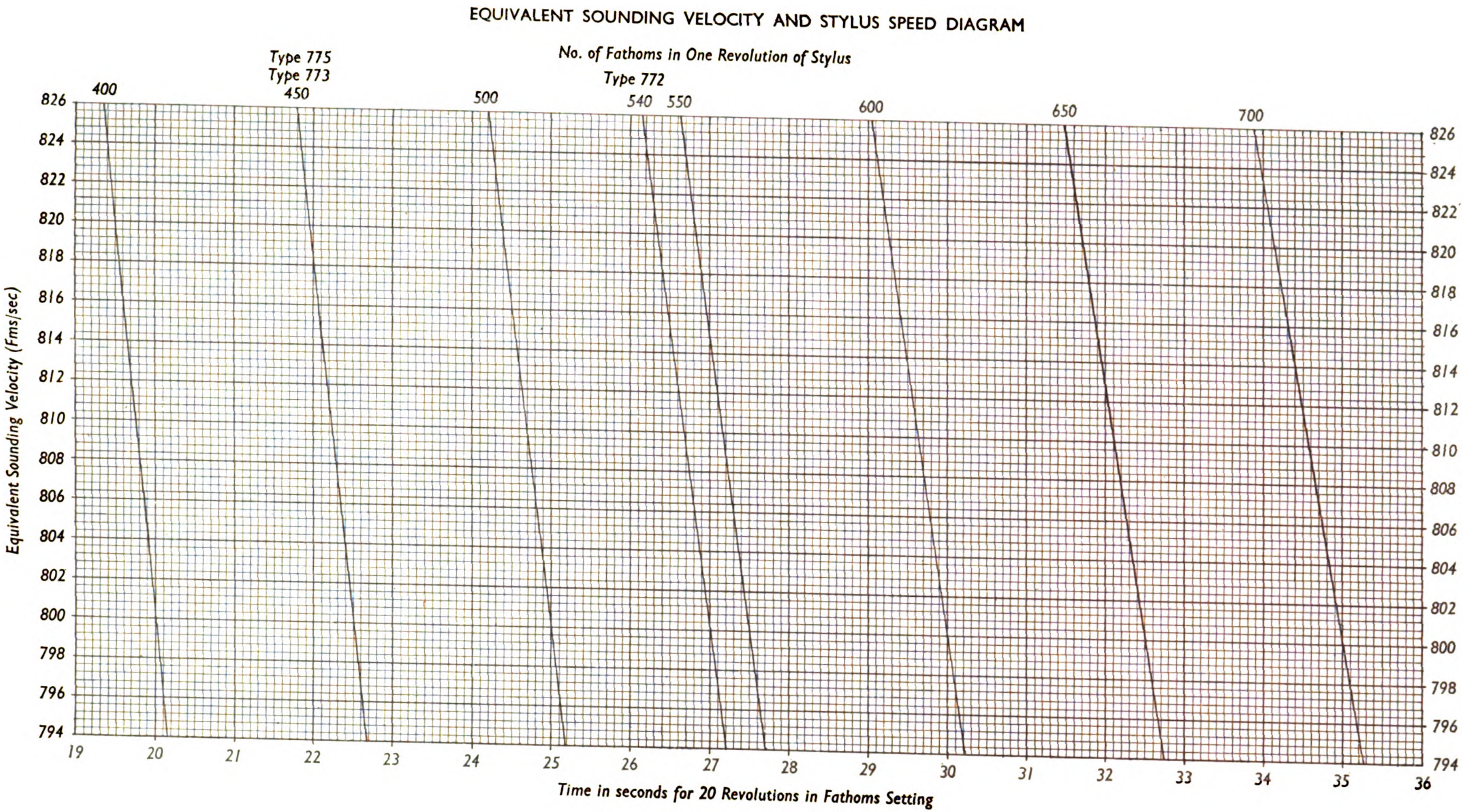
EQUIVALENT SOUNDING VELOCITY AND STYLUS SPEED DIAGRAM
No. of Fathoms in One Revolution of Stylus
Type 775
Type 773
Type 772
400
450
500
540
550
600
650
700
Equivalent Sounding Velocity (Fms/sec)
826
824
822
820
818
816
814
812
810
808
806
804
802
800
798
796
794
Time in seconds for 20 Revolutions in Fathoms Setting
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36

Fig. 3–19(a)

EQUIVALENT SOUNDING VELOCITY AND STYLUS SPEED DIAGRAM

Type 771

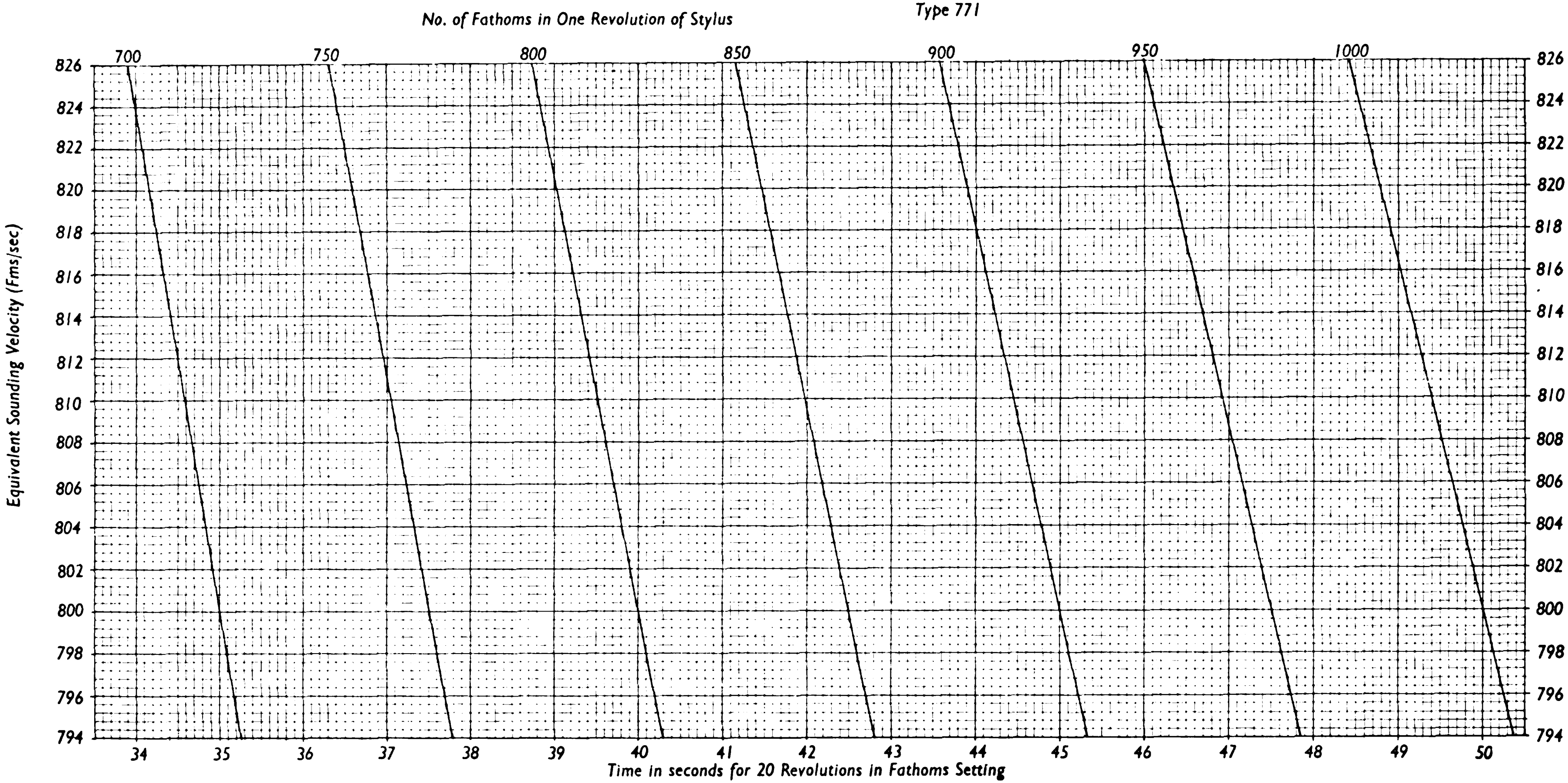

Fig. 3–19(b)

fathoms there are in one revolution of the stylus; e.g., in Type 771 the value is 900 fathoms. Referring to the figures, suppose that with Type 771 the stylus takes 43·9 seconds to make 20 revolutions, then the equivalent sounding velocity is 820 fms/sec. Had the stylus taken 45·0 seconds to make 20 revolutions, the equivalent sounding velocity would have been 800 fms/sec. By using the figures the equivalent sounding velocity corresponding to any stylus speed may be obtained; conversely an equivalent sounding velocity may be chosen and the appropriate stylus speed set. The figures may also be used to determine the error in apparent depth associated with any change of stylus speed. Suppose, for example, that with Type 771 a check reveals that the stylus is making 20 revolutions in 44·2 seconds, whereas it ought to be taking 43·9 seconds. The equivalent sounding velocity is 814·5 fms/sec.; this ought to be 820 fms/sec.; the error is therefore

$$\frac{820-814\cdot5}{820}=\frac{5\cdot5}{820}=0\cdot67\%$$

Common sense indicates that the machine is running too slowly; true depths will therefore be 0·67% greater than apparent depths.

c. Velocity conversion factors

If the equivalent sounding velocity of any echo sounder is determined, the apparent depths obtained may be converted to depths corresponding to any other equivalent sounding velocity by multiplying them by the factors given in the table overleaf.

d. The bar check

For harbour and coastal surveys the bar check method of calibrating an echo sounder is the best available (1964). It may be used by ships or boats. The equipment required is simple to make on board. Using it, the calibrating procedure may take anything between 10 minutes and about an hour, depending on the initial state of adjustment of the echo sounder. In depths of up to about 15 fathoms a bar check calibration will determine the index error and enable the surveyor to match the equivalent sounding velocity of the machine precisely with the average velocity of sound in the water column concerned.

Accurate bar check readings cannot generally be obtained at depths greater than about 15 fathoms. For this reason a set adjusted by this method will only be properly calibrated down to this depth. In a coastal survey where depths vary between say 0 and 100 fathoms, it is probably best to accept this limitation and the resulting fact that depths greater than 15 fathoms may contain errors.* The only practical alternative would be to measure the speed of sound in these greater depths by the time consuming methods referred to in Section **4a** above.

The conditions most suited to the bar checking of a ship's echo are a calm sea, little or no wind, and a depth greater than 90 feet; very reasonable results may, however, be obtained in winds of force 4 or 5, provided there is not too much sea or swell. In boats, the calibration should be carried out if possible in water deeper than the deepest depths likely to be met whilst sounding; calm conditions are necessary for good results.

An echo set should normally be bar checked before and after a day's work. However, if it is well maintained and known to give stable results over long periods, it may well be possible to reduce the number of calibrations to one a day. There is no point in attempting to bar check if the weather conditions are unsuitable.

(i) Bar check equipment. Fig. 3–20 shows a typical bar check. It consists of a

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* However, if the set is well calibrated down to a depth of 15 fathoms, errors at 100 fathoms should not be more than a fathom or two.

ECHO SOUNDING VELOCITY CONVERSION FACTORS

Equivalent Sounding Velocity of Echo Sounder (fms/sec.)

Equivalent Velocity Required (fms/sec.)

	825	824	823	822	821	820	819	818	817	816	815	814	813	812	811	810	809	808	807	806	805	804	803	802	801	800	799	798	797	796	795	
825	1	1·001	1·002	1·004	1·005	1·006	1·007	1·009	1·010	1·011	1·012	1·014	1·015	1·016	1·017	1·019	1·020	1·021	1·022	1·024	1·025	1·026	1·027	1·029	1·030	1·031	1·033	1·034	1·035	1·036	1·038	825
824	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	17	19	20	21	22	24	25	26	27	29	30	31	33	34	35	36	824
823	76	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	17	19	20	21	22	24	25	26	27	29	30	31	33	34	35	823
822	64	76	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	17	19	20	21	22	24	25	26	27	29	30	31	33	34	822
821	52	64	76	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	17	19	20	21	22	24	25	26	28	29	30	31	33	821
820	39	51	64	76	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	17	19	20	21	22	24	25	26	28	29	30	31	820
819	27	39	51	64	76	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	17	19	20	21	22	24	25	26	28	29	30	819
818	15	27	39	51	63	76	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	17	19	20	21	22	24	25	26	28	29	818
817	03	15	27	39	51	63	76	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	17	19	20	21	23	24	25	26	28	817
816	0·9891	03	15	27	39	51	63	76	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	17	19	20	21	23	24	25	26	816
815	79	0·9891	03	15	27	39	51	63	76	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	17	19	20	21	23	24	25	815
814	67	79	0·9891	03	15	27	39	51	63	75	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	17	19	20	21	23	24	814
813	55	67	78	0·9891	03	15	27	39	51	63	75	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	18	19	20	21	23	813
812	42	54	66	78	0·9890	02	15	27	39	51	63	75	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	18	19	20	21	812
811	30	42	54	66	78	0·9890	02	14	27	39	51	63	75	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	18	19	20	811
810	18	30	42	54	66	78	0·9890	02	14	26	39	51	63	75	0·9988	1	01	02	04	05	06	07	09	10	11	12	14	15	16	18	19	810
809	06	18	30	42	54	66	78	0·9890	02	14	26	39	51	63	75	0·9988	1	01	02	04	05	06	07	09	10	11	13	14	15	16	18	809
808	0·9794	06	18	30	42	54	66	78	0·9890	02	14	26	38	51	63	75	0·9988	1	01	02	04	05	06	07	09	10	11	13	14	15	16	808
807	82	0·9794	06	18	29	41	53	66	78	0·9890	02	14	26	38	51	63	75	0·9988	1	01	02	04	05	06	07	09	10	11	13	14	15	807
806	70	82	0·9793	05	17	29	41	53	65	77	0·9890	02	14	26	38	51	63	75	0·9988	1	01	02	04	05	06	07	09	10	11	13	14	806
805	58	69	81	0·9793	05	17	29	41	53	65	77	0·9889	02	14	26	38	51	63	75	0·9988	1	01	02	04	05	06	08	09	10	11	13	805
804	45	57	69	81	0·9793	05	17	29	41	53	65	77	0·9889	01	14	26	38	50	63	75	0·9988	1	01	02	04	05	06	08	09	10	11	804
803	33	45	57	69	81	0·9793	05	17	29	41	53	65	77	0·9889	01	14	26	38	50	63	75	0·9988	1	01	02	04	05	06	08	09	10	803
802	21	33	45	57	69	80	0·9792	04	16	28	40	53	65	77	0·9889	01	13	26	38	50	63	75	0·9988	1	01	02	04	05	06	08	09	802
801	09	21	33	45	56	68	80	0·9792	04	16	28	40	52	65	77	0·9889	01	13	26	38	50	63	75	0·9988	1	01	03	04	05	06	08	801
800	0·9697	09	21	32	44	56	68	80	0·9792	04	16	28	40	52	64	77	0·9889	01	13	26	38	50	63	75	0·9988	1	01	03	04	05	06	800
799	85	0·9697	08	20	32	44	56	68	80	0·9792	04	16	28	40	52	64	76	0·9889	01	13	25	38	50	63	75	0·9987	1	01	03	04	05	799
798	73	84	0·9696	08	20	32	44	56	67	79	0·9791	03	15	28	40	52	64	76	0·9888	01	13	25	38	50	63	75	0·9987	1	01	03	04	798
797	61	72	84	0·9696	08	20	31	43	55	67	79	0·9791	03	15	27	40	52	64	76	0·9888	01	13	25	38	50	62	75	0·9987	1	01	03	797
796	48	60	72	84	0·9695	07	19	31	43	55	67	79	0·9791	03	15	27	39	51	64	76	0·9888	01	13	25	38	50	62	75	0·9987	1	01	796
795	36	48	60	72	83	0·9695	07	19	31	43	55	67	79	0·9791	03	15	27	39	51	64	76	0·9888	00	13	25	37	50	62	75	0·9987	1	795
	825	824	823	822	821	820	819	818	817	816	815	814	813	812	811	810	809	808	807	806	805	804	803	802	801	800	799	798	797	796	795	

NOTE: Linear interpolation between tabulated values is quite safe.

Example: The equivalent sounding velocity of an echo sounding machine is 814·5 fms/sec. It is required to convert depths to an equivalent sounding velocity of 820 fms/sec. From the table, the conversion factor is 1·0065 (±0·0005).

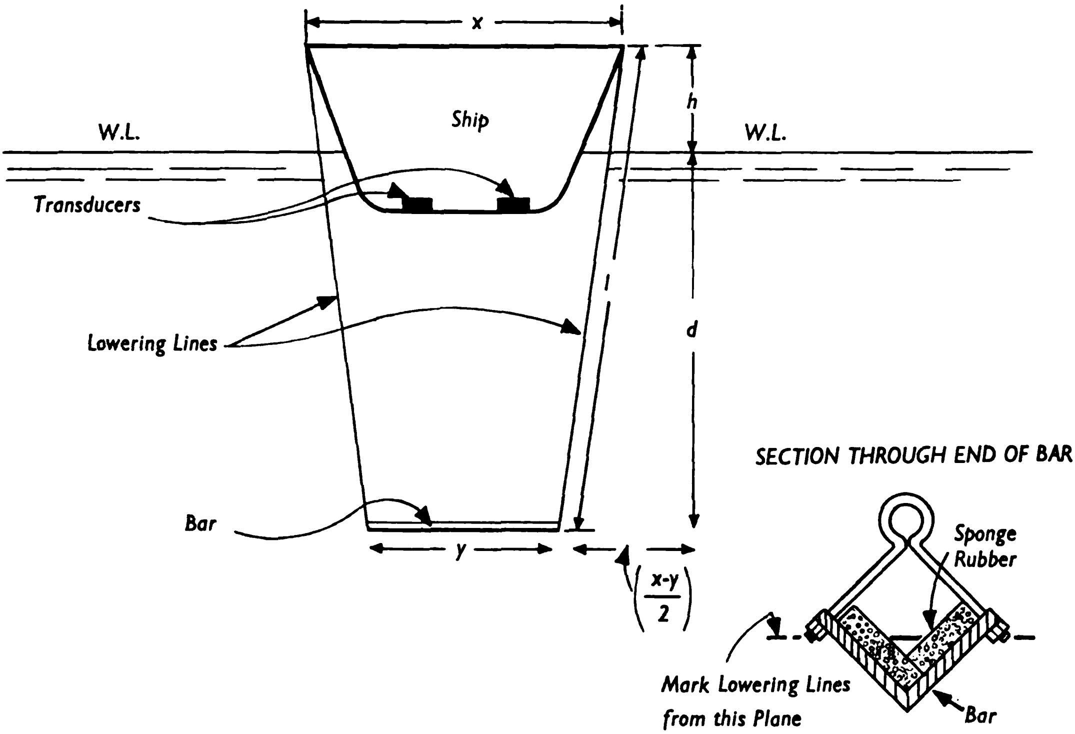
x
Ship
W.L.
W.L.
h
Transducers
l
Lowering Lines
d
SECTION THROUGH END OF BAR
Bar
y
$\left(\frac{x-y}{2}\right)$
Sponge Rubber
Mark Lowering Lines from this Plane
Bar

Fig. 3–20

length of angle bar that may be lowered to various known depths below the echo sounding transducers on two marked lowering lines.

The bar itself should be slung apex downwards. The inner faces of the angle should be lined with a material containing a large proportion of trapped air; sponge rubber or foam plastic is very suitable. This lining, which should be between half an inch and one inch thick, forms an excellent reflecting surface for sound waves in water. If possible the length of the bar should be equal to the beam of the vessel at the transducers; the lowering lines will then hang vertically. Bars over about 18 feet long are rather heavy to rig by hand, and unless they are of large cross sectional area, tend to sag in the middle; therefore, those designed for use with ships are generally shorter than the vessel's beam. Their lowering lines will no longer hang vertically and must be marked to compensate for this fact.

Referring to Fig. 3–20, it can be seen that the lowering lines are well clear of the turn of the vessel's bilge. It is important that they should never be allowed to lead round the bilges; if this happens, the corrections shown in the bar check marking diagram (Fig. 3–21) will no longer be valid. If the bar is very much shorter than the beam of the ship it may be necessary to increase the distance x in Fig. 3–20 by rigging spars.

It is recommended that bar check lowering lines should be made of flexible steel wire rope. This material is easy to handle, does not stretch, and cannot be mistaken for an ordinary leadline. If the lines are marked at every fathom for ship work, and every half fathom for use in boats, there will be less chance of their being used for the wrong purpose.

(ii) Marking the lowering lines; the bar check marking diagram. If the length of the bar is equal to the beam of the vessel at the transducers, the lowering lines will hang vertically. They may therefore be marked in the normal way, and required depths may be set against the water-line.

If the length of the bar is less (or greater) than the beam of the vessel at the transducers, the lowering lines will no longer hang vertically, and must be marked in a special way to compensate for this fact.

Referring to Fig. 3–20,

$$l^2 = \left(\frac{x-y}{2}\right)^2 + (d+h)^2$$

$$= \tfrac{1}{4}(x-y)^2 + (d+h)^2$$

$$\therefore l = \sqrt{\tfrac{1}{4}(x-y)^2 + (d+h)^2}$$

where l = Length of lowering line
x = Beam of vessel at transducers
y = Length of bar
d = Depth of bar below water-line
and h = Height of deck above water-line.

Note that the length l of the lowering line is measured from the deck level (or chains) and *not* the water-line. This is important. If this is not done, and the water-line is used, then for a ship's beam of 32 feet, a bar length of 17 feet, and a freeboard of 18 feet, errors will be six inches if the bar is set to 12 fathoms below the surface, and one and a quarter feet if it is set to three fathoms.

Fig. 3–21 gives the corrections which must be applied when marking a lowering line, for various values of $(d+h)$ and $(x-y)$. The fathoms marks on the line will always be more than a fathom apart.

(iii) Bar check procedure. The procedure outlined below applies to a large vessel where the length of the bar is less than the beam of the ship at the transducers. Procedure in a boat will be simplified by the fact that the length of the bar will almost certainly equal the beam of the boat; the lowering lines will hang vertically, and may be set against the water-line.

If the echo sounder is known to be out of adjustment, the transmission line should be set roughly to the draught of the transducers (a foot or so either way is not important), and the equivalent sounding velocity of the machine should be adjusted to a value between 800 and 820 fms/sec.*, before carrying out the bar check procedure, which is as follows:

(1) Switch on the echo sounder about 10 minutes before it is required; it should be set to measure feet.

(2) Stop the ship in the water, in a depth preferably greater than 90 feet. If there is any wind it will probably be best to put it right astern.

(3) Lower the bar into the water, pay out the lowering lines and set them against the edge of the chains or upper deck, so that the bar is about 90 feet below the surface. For instance, a setting of 18 fathoms made against chains 19 feet above the water-line will produce a bar depth of 108 − 19 = 89 feet. If the water is less than 90 feet deep, set the lowering lines (to the nearest fathom) so that the bar is as close to the bottom as possible. The lines must be in the same vertical plane as the transducers, and the ship must be handled so as to keep them 'up and down'.

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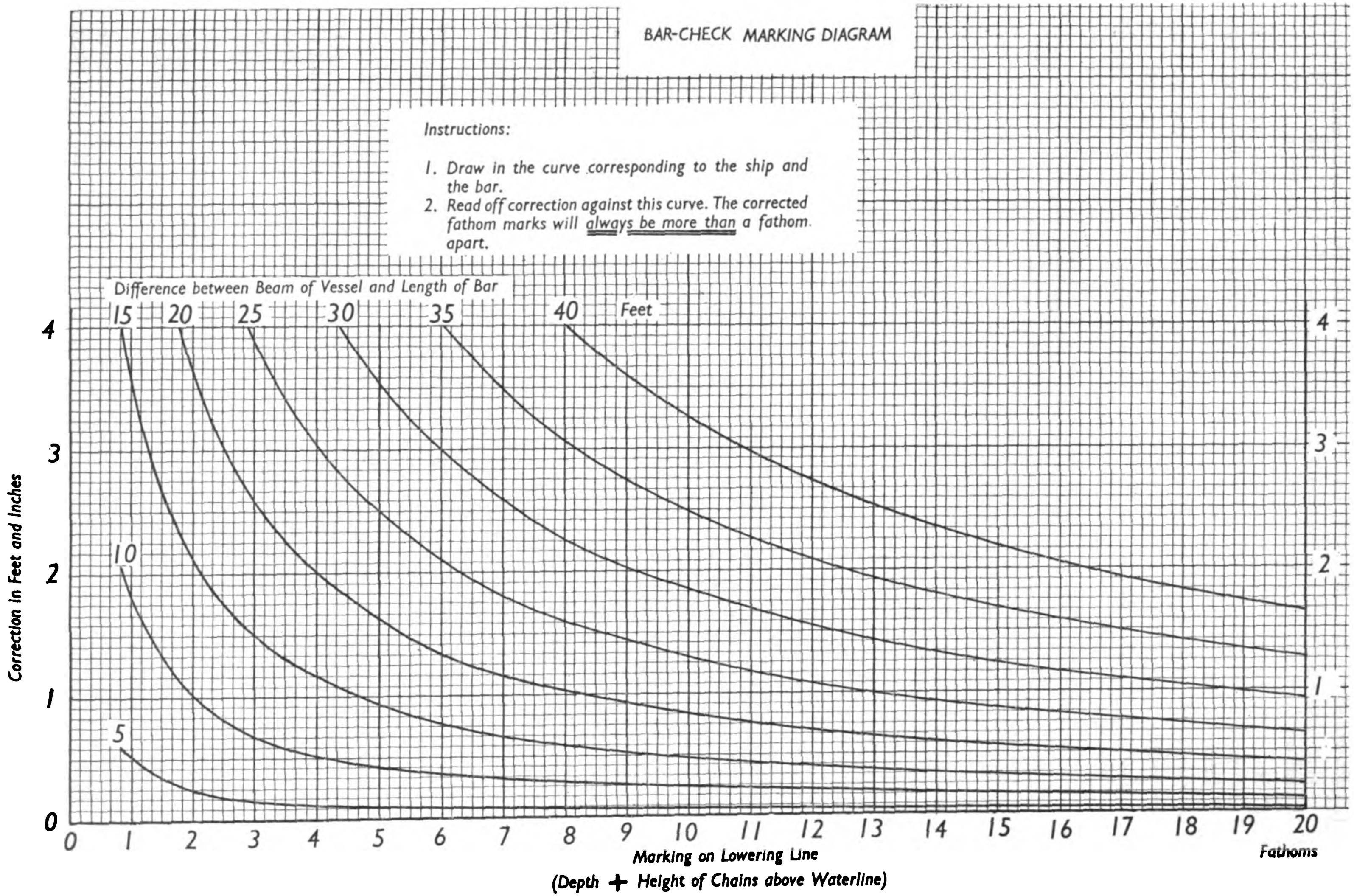
* If the velocity of sound in the water concerned can be estimated, this value should be used.



BAR-CHECK MARKING DIAGRAM

Instructions:

1. Draw in the curve corresponding to the ship and the bar.
2. Read off correction against this curve. The corrected fathom marks will always be more than a fathom apart.

Fig. 3–21

(4) Provided the bar reflects well and is vertically below the transducers, a strong echo from it should be visible on the recorder trace. Its depth should be read off on the scale when the lowering lines are up and down, and noted.

(5) Raise the bar two fathoms (lowering lines to 16 fathoms and bar to 77 feet in this case), and repeat (4) for this setting. Obtain readings in this way every two fathoms between about 90 feet and 18 feet.

(6) Apply the separation correction where necessary, and tabulate echo sounder depths against the true depths of the bar. Note against each true depth the error of the echo at that depth. The following table shows how this may be done:

Separation of transducers = 6 feet
Draught of transducers = 10 feet
Height of chains above water-line = 19 feet

1 LOWERING LINE SETTING AGAINST CHAINS	2 DEPTH OF BAR	3 ECHO DEPTH	4 SEPARATION CORRECTION (FROM FIG. 3–15)	5 ECHO DEPTH CORRECTED FOR SEPARATION	6 ECHO SOUNDER ERROR (COL. 2∼5)
fms	*ft*	*ft*	*ft*	*ft*	
18	89	91	Negligible	91	Echo is 2 ft deep
16	77	79	,,	79	,, ,, 2 ,, ,,
14	65	66	,,	66	,, ,, 1 ,, ,,
12	53	54	,,	54	,, ,, 1 ,, ,,
10	41	41	,,	41	,, ,, correct
8	29	29	¼	28¾	,, ,, ¼ ft shallow
6	17	17¼	¾	16½	,, ,, ½ ,, ,,

(7) Plot on graph paper the error of the echo against true depth of the bar. Fig. 3–22 shows the plot made from columns 2 and 6 of the table above. Draw in the straight line that fits the plotted points best; it is shown pecked in the figure.

(8) The following information can now be taken from the bar-check plot:

(i) *The random errors of the bar-check observations.* It can be seen in Fig. 3–22 that no plotted point is more than 0·3 foot in echo depth away from the pecked line.

(ii) *The index error of the echo sounder.* It is 'one foot shallow', and is measured from the point *x* to the base line. The point *x* is at a bar depth of 10 feet, since the draught of the transducers is 10 feet. Note that the bar depth of *x* could be varied by two feet or so either way without affecting the index error by more than an inch or two. Since the index error is 'one foot shallow', one foot must be added to all echo depths to obtain true depths.

(iii) *The speed error of the echo sounder.* The recorder motor is running too fast, since the deeper the true depth, the greater becomes the excess of echo depth over it. In this case it is running too fast by an amount equal to 3/73½, or one part in 24½.

(9) Provided the index error is not too great, no attempt should be made to remove it, unless the transmitting contacts are very easy to adjust. It may be allowed for when soundings obtained in the field are reduced to chart datum.

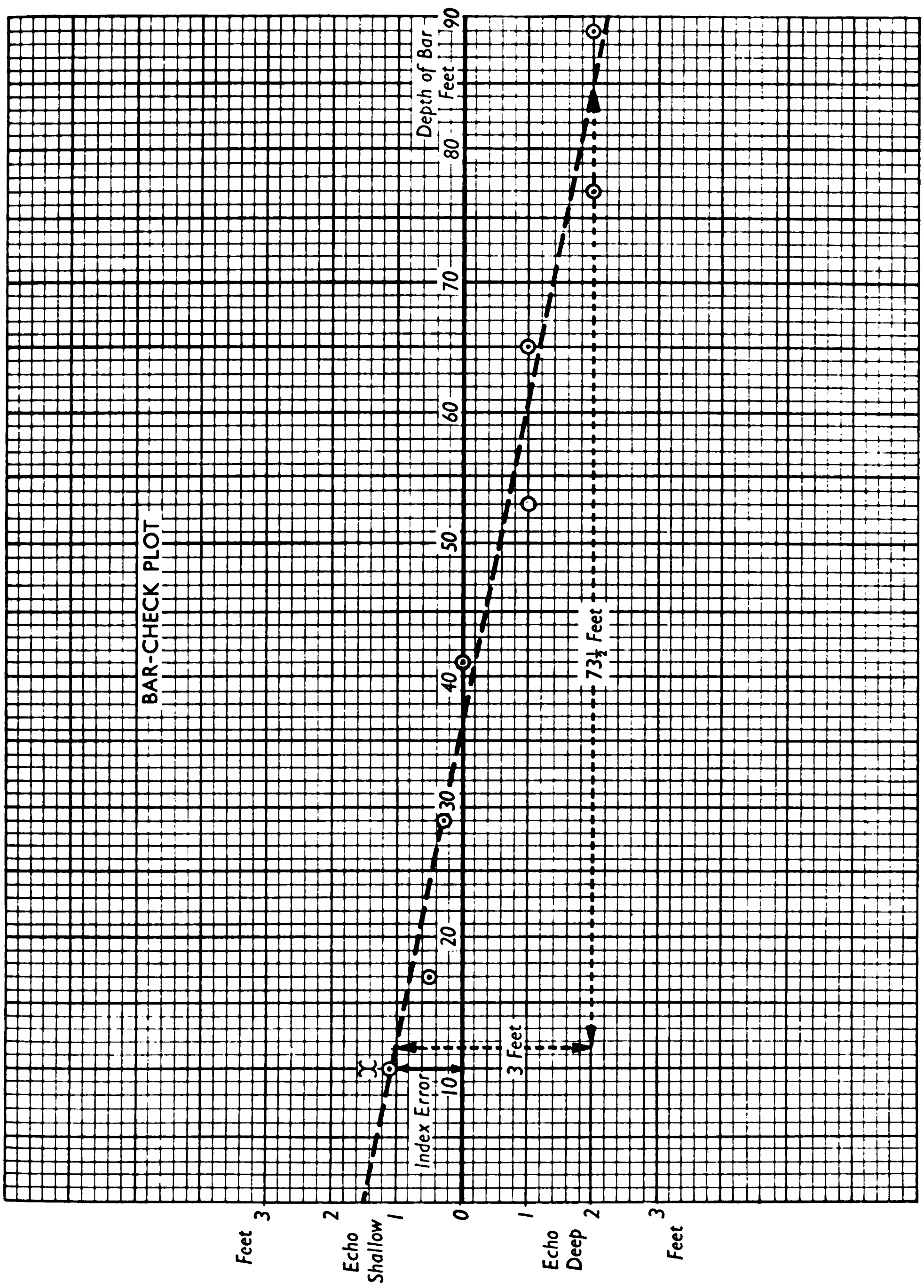


Fig. 3–22

Speed error, however, can only be allowed for by applying an awkward percentage correction to soundings obtained in the field. It should therefore be removed at the outset. This may be done in the following way:

Referring to Fig. 3–22, the speed error is one part in 24½ fast. Suppose that the bottom echo on the recorder trace is at an apparent depth of 102 feet. If the motor governor is adjusted to make this depth read

$$102 - \frac{102}{24\frac{1}{2}} = 97\tfrac{3}{4} \text{ feet}$$

the equivalent sounding speed of the echo will be matched exactly with the speed of sound in the water column concerned, and all echo depths will be one foot shallow (on account of the index error). The effect of this speed adjustment on the plot would be to cause the pecked line to pivot about the point x until it was horizontal.

(10) Having made the speed adjustments outline in (9) above, and having adjusted the transmitting contacts to reduce the index error, if this is necessary, the entire bar check procedure should be repeated, as a check. If the initial adjustments have been well made, the discrepancy between echo depths (corrected for separation error) and bar depths will be constant at all depths. There will be no need to make a second plot; the index error of the equipment will equal the constant discrepancy.

(11) When the calibration has been completed, the depth of the transmission line should be noted, and the speed of rotation of the stylus should be timed with a stopwatch. These values can then be used to check that the recorder behaves in a stable manner whilst sounding is in progress.

In practice, provided the initial bar check calibration is carried out carefully, and the water qualities do not vary,* day-to-day calibrations should produce plots in which the slope of the lines varies by less than one part in 100 from the horizontal. Most of them will be completed in less than 15 minutes, and there will be no need to plot at all in many cases. The index error will, of course, vary with changes in the ship's draught and trim, though probably not as much as might be expected.

Fig. 3–23 shows the echo trace obtained by a boat whilst carrying out a bar check calibration. Note that in this case the bar has been lowered in steps from six feet to 48 feet. This practice, rather than that outlined above, where the bar is raised in steps from deep to shallow settings, may be followed if desired. However, experience indicates that in a ship the bar will be easier to handle, and echoes from it will be easier to hold, if it is set deep to start with.

(12) The adjustment of the set in the fathoms measuring setting is simple, provided the procedure outlined above has first been carried out. The depth of the bottom, measured in fathoms, should be made to agree with the depth measured in feet, by adjusting the fathoms transmitting contacts. The index error in the feet measuring position must be allowed for if it is measureable in the fathoms setting; speed errors will affect the two readings equally, and need not be taken into account in this adjustment. Once it has been set satisfactorily, the depth of the transmission line in the fathoms setting should be noted for future reference.

e. Calibrating without a bar check

If bar checking equipment is not available, the method outlined below may be used. It is at best only a comparatively rough and ready method, which in the hands of an inexperienced surveyor may fail to detect, or even introduce, quite large errors. In what follows, it is assumed that the principles set out in Section **4d** above have been grasped.

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* In practice, day-to-day variation is not likely to be measurable, except in estuaries, where the salinity and temperature of the water will very probably change as the tidal streams carry volumes of salt or fresh water from place to place.

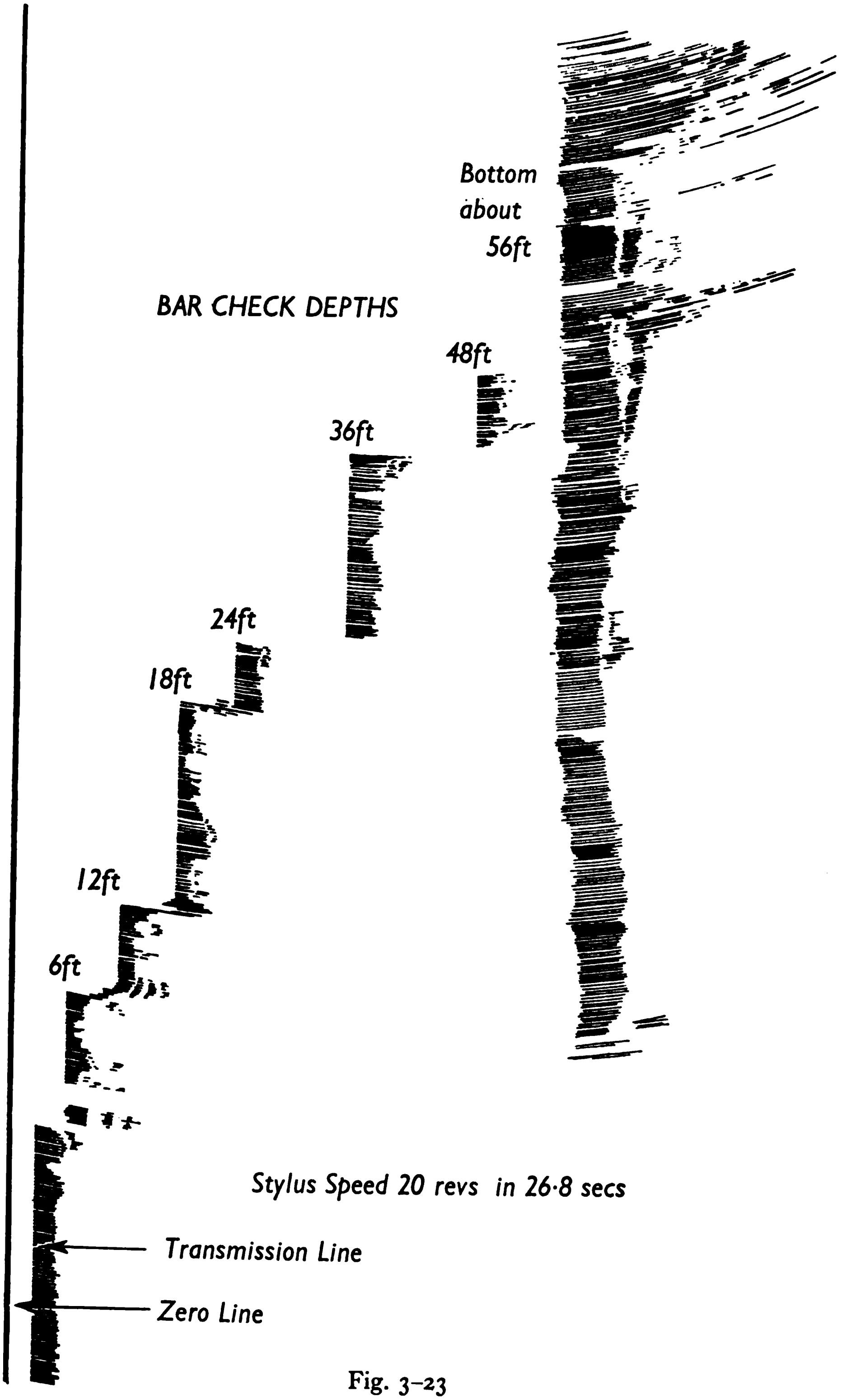

Bottom
about
56ft
BAR CHECK DEPTHS
48ft
36ft
24ft
18ft
12ft
6ft
Stylus Speed 20 revs in 26·8 secs
Transmission Line
Zero Line

Fig. 3–23

The procedure, which follows that of bar checking as closely as possible, is as follows:

(1) Obtain comparisons between echo sounding depths and depths obtained by an up and down wire or leadline over as great a range of depth as possible. It is important that this range should be at least as great as that likely to be encountered whilst sounding; if it is not, then errors will almost certainly be present. Several readings should be obtained at each comparison, and noted. Corrections for separation of the transducers must be applied, if necessary.

(2) Plot the error of the individual echo readings against wire or leadline depth, and then proceed as if a bar check had been carried out. *See* Section **4d(iii)** above.

Example

A vessel whose draught at the transducers is about 12 feet, wishes to sound out an area where the depths vary between three fathoms and 10 fathoms. The separation between her transducers is five feet.

The transmission line on the echo is set to 12 feet, and the speed of rotation of the stylus adjusted to an equivalent sounding velocity of 800 fms/sec. The following comparisons are then obtained:

1 LEADLINE DEPTH	2 ECHO DEPTH	3 SEPARATION CORRECTION	4 ECHO DEPTH CORRECTED FOR SEPARATION	5 ECHO SOUNDER ERROR (COL. 1~4)
ft	*ft*	*ft*	*ft*	
17	18½	½	18	Echo is 1 ft deep
17½	18½	½	18	,, ,, ½ ,, ,,
18½	18½	½	18	,, ,, ½ ,, shallow
ft	*ft*		*ft*	
37	36	Negligible	36	Echo is 1 ft shallow
39	38	,,	38	,, ,, 1 ,, ,,
37½	38	,,	38	,, ,, ½ ,, deep
38	39½	,,	39½	,, ,, 1½ ,, ,,
ft	*ft*		*ft*	
64	64	Negligible	64	Echo is correct
66½	65½	,,	65½	,, ,, 1 ft shallow
64	62	,,	62	,, ,, 2 ,, ,,
65½	65	,,	65	,, ,, ½ ,, ,,

Fig. 3–24 shows the leadline calibration plot. From it the following information may be obtained:

(1) *The random errors of the observations*, which vary between an inch or two and about one and a half feet. These errors result from the fact that the bottom was soft and not quite flat, and the leadline possibly not quite up and down. The reliability of the calibration may be estimated from these random errors; this is the reason why the readings at each depth have been plotted individually, and not meaned before plotting. The greater these random errors, the worse the calibration becomes; in this case it is very unlikely that the pecked line is in error by more than half a foot or so.

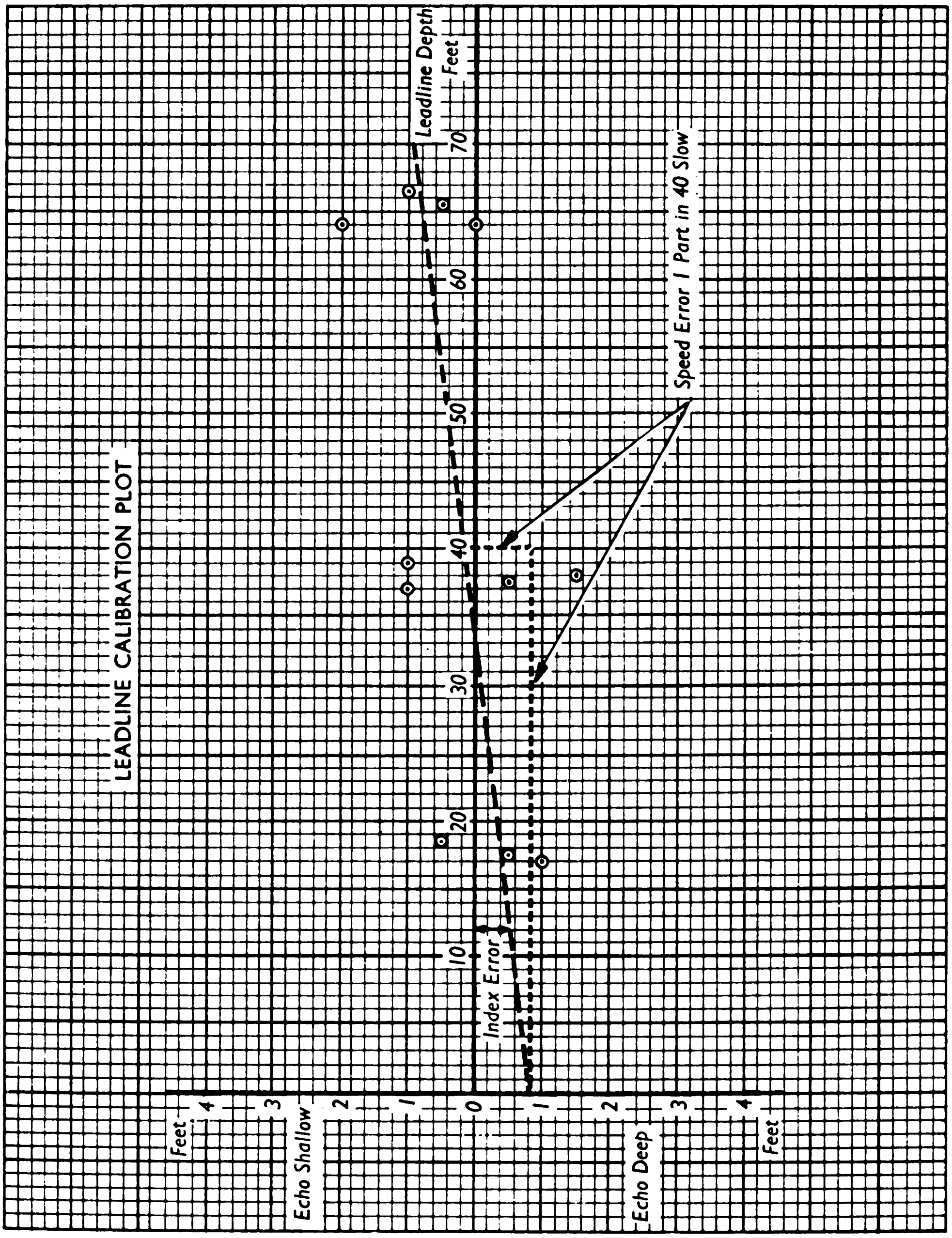


Fig. 3–24

(2) *The index error of the echo sounder.* In this case it is 'half a foot deep'.

(3) *The speed error of the machine.* Here it is running too slowly by one part in 40. If there is not time to obtain comparisons at three or more depths, then the shallow and deep comparisons should have priority. Note that a comparison at one depth only is generally valueless, since neither the index error nor the speed error can be determined from it. The only occasion when a comparison at one depth only is permissible is when the bottom is quite flat and featureless; in these circumstances there is no need to find out the index or speed errors so long as the error at the constant depth is known.

5. False Echoes

The traditional term 'false echo' is really a misnomer; it is used by the surveyor to describe a marking on the echo trace that is not the main object of interest. Thus, the echo from a shoal of fish would be classified as a false echo by the surveyor whose main interest was the delineation of the bottom features. Most false echoes are in fact only too real. Sometimes it is very difficult indeed to decide whether a shoal echo is 'false' or true, and on occasions much patience and ingenuity is required to determine its nature without any reasonable doubt.

One of the main tasks of the hydrographic surveyor is to find, fix, and obtain the least water over all natural or man-made objects which form part of, or lie on the sea bed, and which, if undetected, may be a danger to navigation. To do this, he must first decide which echo, possibly out of several, is returning from the sea bed or a solid and dangerous object lying on it, and which, being 'false', can be disregarded. No hard and fast rules can be laid down to help him; the whole process is an art rather than a science, and experience is probably the best weapon in the surveyor's armoury.

One point is most important: no echo must ever be assumed to be 'false' if any doubt at all remains that it might possibly be dangerous to surface or submarine navigation.

The table below lists the causes of some false echoes; it is as comprehensive as it is

THE CAUSES OF SOME FALSE ECHOES

CAUSE	REMARKS
Fish (*See* Sect. **5a**)	
In the open sea	Not very common. Relatively easy to identify
Over rock pinnacles	Difficult to identify
Over coral heads	Can be very difficult to identify
Water Layers (*See* Sect. **5b**)	
In the open sea	Not very common. Usually simple to identify
Over growing coral	Can be very difficult to identify
Deep scattering Layer (*See* Sect. **5c**)	Not very common. Usually found in fairly deep water and simple to identify
Fresh Water Springs (*See* Sect. **5d**)	Very common in some areas. Some are simple, others very difficult to identify
Kelp or Weed (*See Sect.* **5e**)	Can be very difficult to identify
Side Echoes (*See* Sect. **5f**)	Usually very important to investigate their cause
Turbulence (*See* Sect. **5g**)	A suspected rather than a proved cause
Instrumental or Man-made (*See* Sect. **5h**)	Can always be avoided by careful maintenance and correct operation

possible to make it (in 1964) but cannot claim to be all embracing. As echo sounders become more sensitive and more powerful, and as our knowledge of the oceans increases, new causes are bound to be detected and identified.

a. False echoes caused by fish

Some fish have swim bladders which they can distend or dilate in order to adjust their buoyancy. These bladders, being filled with gas, will reflect sound waves in water and make an echo on a sounding trace. The nature of this echo will depend on the type, number and disposition of the fish concerned.

(i) Fish in the open sea. In the open sea fish echoes are comparatively easy to identify, unless the fish are lying very close to the bottom. In many cases, the echo will be quite distinct from the bottom, and the bottom echo will be clearly visible through it. If there is any doubt, the recorder should be switched to the slow speed and the gain increased as much as possible; this will tend to strengthen a weak bottom echo. The use of an echo sounder having a lower frequency will also tend to strengthen a bottom echo masked by a dense shoal of fish.

Fig. 3–25(a) shows a sounding trace obtained by a trawler in comparatively deep water. The saw tooth form of the fish and bottom echoes is caused by the vessel's movement in a swell. These fish are swimming in a dense shoal, which gives a strong echo; nevertheless the bottom is clearly visible through it.

The trace in Fig. 3–25(b) was obtained in shallower water. The fish are swimming in small groups, which produce the lozenge shaped echoes well clear of the bottom. This type of echo is fairly characteristic of fish; each lozenge is probably produced by several fish, lying at slightly different depths. The small apparent shoals at x are much more difficult to classify. They could be caused by fish lying close to the bottom; on the other hand they could equally well come from small outcrops forming part of the bottom. The surveyor would be wise to assume that they were the latter, unless he had strong evidence external to the echo trace, to the contrary.

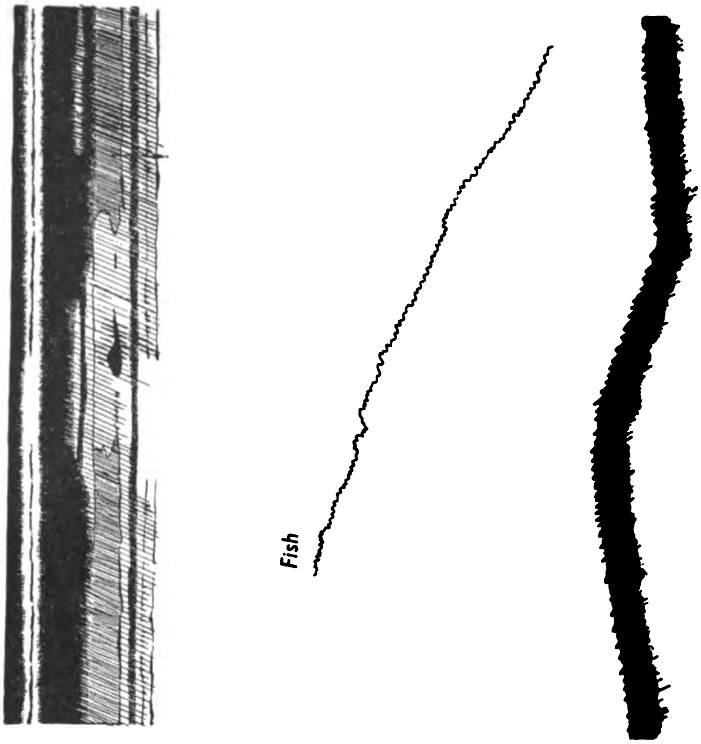
(ii) Fish over rock pinnacles and coral heads. Over rock pinnacles and coral heads it will usually be extremely difficult to distinguish false echoes caused by fish from those caused by weed and other substances. Small fish have been seen swimming over a coral head which produced an echo trace very similar to that shown in Fig. 3–26. They could have caused the false echoes at y and z, but it would be foolish to assume that they had from the evidence of the echo sounding trace alone.

b. False echoes caused by water layers

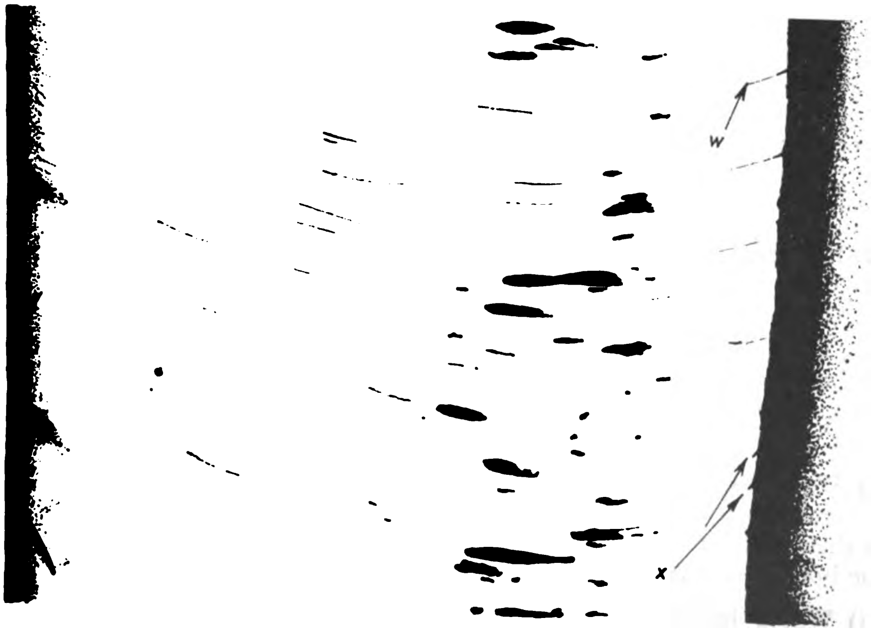
Whenever a sound wave passes from one medium into another in which its velocity is different, refraction will take place. In certain circumstances partial reflection may occur, i.e. some of the sound will be reflected and some, being refracted, will pass on into the new medium. In the extreme case the reflection may be virtually complete. The higher the frequency of the echo sounder the greater the refraction will be, and the greater will be the possibility of reflection taking place.

(i) Water layers in the open sea. False echoes caused by water layers in the open sea are not very common. It will be most unlikely that they will cause a total reflection of the sound energy, and they will therefore usually be rather nebulous in character; the bottom echoes should be clearly visible through them.

(ii) Water layers over growing coral. Some growing corals seem to exude a substance into the water immediately above and around them, which gives it a slightly opaque and milky appearance, and which can be seen by divers. Fig. 3–26 shows the sort of echo trace which has been obtained over such a coral head. The false echoes at y and z may be caused by partial reflection at the boundary; on the other



(a) A shoal of fish in comparatively deep water



(b) Small groups of fish lying well clear of the bottom

Fig. 3–25

FALSE ECHOES OVER AND AROUND A SHOAL

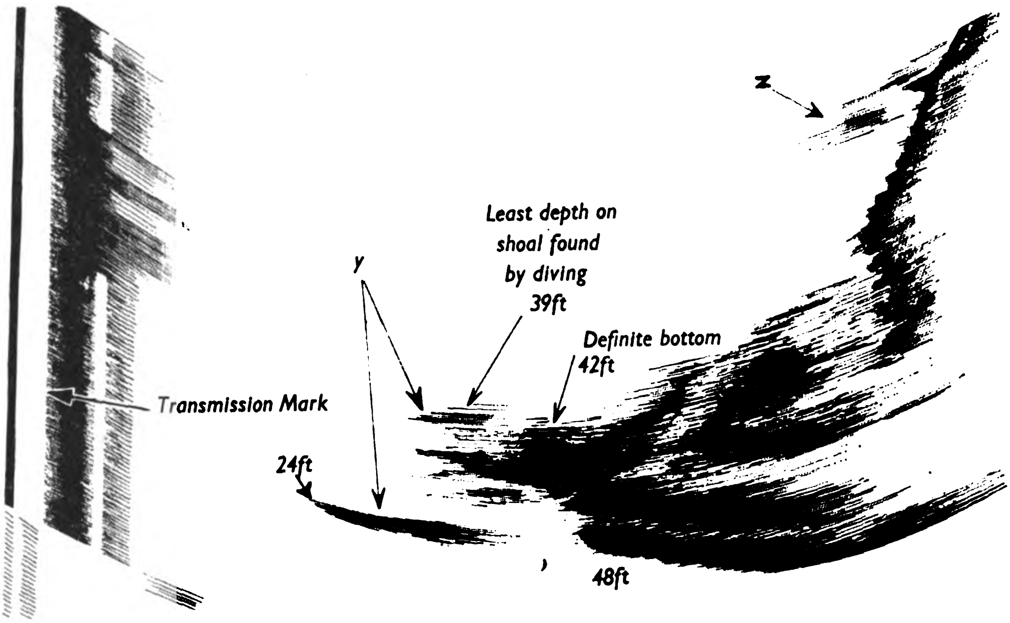


Fig. 3–26

hand they could equally well have been caused by the small fish that were seen to be swimming about (*see* **a(ii)** above); there was no weed of any sort growing on the coral head in question.

c. False echoes caused by the deep scattering layer

Some forms of plankton reflect sound waves quite strongly if they are present in sufficient numbers. The deep scattering layer is thought to consist of these plankton, which lie at a depth of about 200 fathoms in daylight. At night the layer has been observed to rise. It will produce strong echoes on an echo sounding trace, and has in the past been one of the most frequent sources of false shoal soundings being reported in deep water. See Section **37a** of this chapter.

d. False echoes caused by freshwater springs

In some parts of the world springs exist on the sea bed. The fresh or brackish water issuing from them can at times produce a strong echo on a sounding trace, which resembles that from a wreck or shoal of small extent. Some springs have been observed to produce strong echoes from the horizontal transmissions of a sonar set. In the southern Persian Gulf, where these springs were first identified, the sea bed consists of sand over stratified layers of sandstone. The springs, which in places are quite numerous, appear to lie along fault lines in the sandstone. It is quite probable that they have some connection with the natural wells which are found ashore in this area.

A weak freshwater spring might well produce an echo similar to that at *w* in Fig. 3–25(b). The trace from a stronger one might resemble the 24-foot echo at *y* in Fig. 3–26. Unless the spring echo is very strong indeed, it will usually be possible to see the sea bed echo through it. Fig. 3–27 shows the echo trace obtained in a vessel moving slowly over a freshwater spring in Weymouth Bay, whilst sweeping for wrecks. The echo from the sweep may be seen passing right through that from the spring.

FALSE ECHO FROM A FRESHWATER SPRING

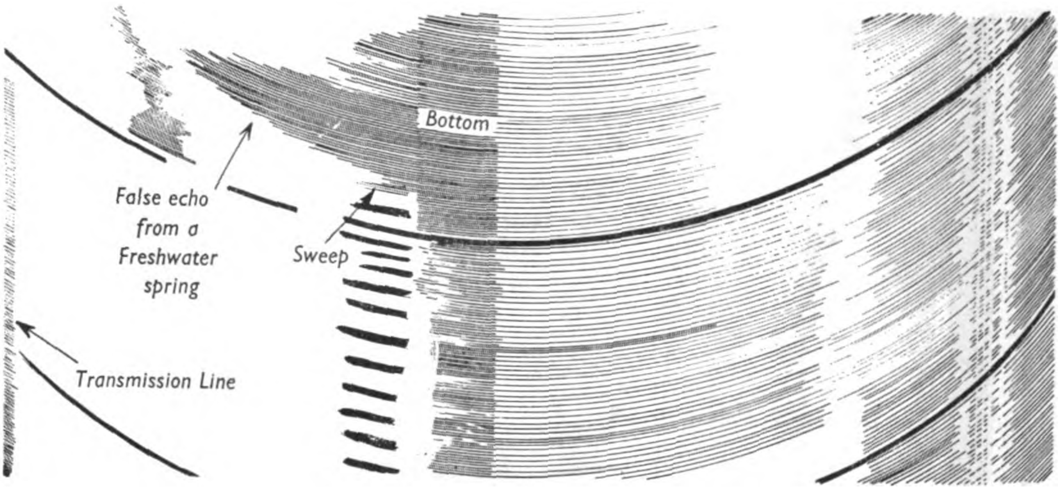


Fig. 3–27

Sweeping is the surest way of proving the falseness of these echoes. Water sampling has also been used to good effect in the past. If a sample of water is collected close to the bottom over a suspected freshwater spring (an insulated or reversing water bottle may be used for this purpose), its salinity may be compared with samples collected half a cable and a mile or two away. If the spring exists, then the salinity of the water immediately over it will be markedly less than that of the sea water some distance away. In two cases in which this test has been carried out the water from the spring was just drinkable, whilst that collected from a point half a cable away was very salty indeed.

Where freshwater springs are found they are quite likely to be very numerous. To identify each one by sweeping or water sampling might well be a most laborious and time consuming task. In such cases the surveyor may identify them by their echoes alone, provided he has first satisfied himself that the rock formation under the sea bed is compatible with their existence and positively identified at least one spring by sweeping or water sampling. Inquiries from the local fisherman may also help. In the southern Persian Gulf the pearl fishers have been obtaining supplies of drinking water from freshwater springs on the sea bed for many years.

e. False echoes from kelp or weed

False echoes from kelp and weed can be very difficult to identify. Although the bottom echo will usually be visible through them, it may on occasions be completely masked. Kelp is not common at depths greater than about 15 fathoms; weed of other types may be found at almost any depth in coastal waters.

If a false echo comes from kelp or weed, sweeping (except by the Oropesa method) will be of very little use in its identification. A leadline may be dropped through it; on occasions it may be possible to bring some to the surface by grappling. Visual identification by divers is probably the best method of dealing with it; in clear waters a water-glass used over the side of a boat might enable the surveyor to see it growing on the bottom.

If the area round a false echo suspected of coming from kelp is examined visually at low-water slack, it should be possible to see traces of it on or below the surface of the water.

f. Side echoes

It was seen in Section **2b(iii)** of this chapter that not all the energy transmitted from an echo sounder is concentrated into the main lobe. Some of it will form side lobes like those illustrated in Fig. 3–2. If one of these side lobes illuminates an object not immediately below the vessel, whose slant depth is less than the depth of water, then a side echo will be produced.

Side echoes may produce traces which are detached from the bottom, blend with it, or mask it completely. Very often they look like the 24-foot echo at *y* in Fig. 3–26.

It will usually be possible to differentiate between a side echo and false echoes from fish, water layers and the deep scattering layer by the circumstances in which it is found. For instance, a side echo reflected from an object lying on the sea bed would not be likely to be found in depths as great as 200 feet. Kelp and weed, when found, will usually be growing over a fairly wide area; however, kelp growing from the top of a rocky pinnacle shoal might easily produce a false echo very like a side echo. Until they were identified, many freshwater springs were suspected of being side echoes off coral heads.

Side echoes are most likely to be obtained from submerged wrecks and other obstructions. They can also appear when a boat is sounding close alongside a harbour wall or jetty.

g. Turbulence

Turbulence in the water, caused by the interaction of tidal streams in the open sea, or at the junction of a tributary with a river, may or may not cause false echoes. False echoes have certainly been obtained where turbulence has been observed, but their cause has not yet been identified with certainty. They might in these circumstances have been reflected from water layers, and not be caused by the turbulence itself.

h. Instrumental and man-made false echoes

Instrumental false echoes can always be avoided by careful maintenance and correct operation. If the transmitting contacts and circuits are well maintained, and there is no backlash in the gears connecting the recorder motor to the stylus arm, they are not likely to occur. It should be remembered that too high a setting of the gain control may introduce spurious marks on the trace at times.

Any noise of the correct frequency arriving at the receiving transducer will be recorded, and in certain circumstances a false echo may be produced. On one occasion the source of a tiresome false echo was finally traced to the engine room of the ship concerned, where an innocent engineer was belabouring a stubborn nut with a sledge hammer. In boats, faulty battery charging circuits, sparking brushes on generators, and mechanical vibration can all create false echoes.

i. True echoes that may appear to be false

Sometimes an echo may be obtained which has all the attributes of falsity, whereas it is in fact only too true. Mooring and other buoys tethered to lie below the surface will produce echoes very like those from fish. Moored mines produce very similar echoes provided they are large enough. Old fishing stakes protruding from the bottom may well produce apparent false echoes. Some types of coral are full of cavities, and others grow long antler like structures; both these forms have been observed to give very realistic apparent false echoes, of the type illustrated in Fig. 3–26.

The surveyor should, therefore, always beware of jumping to conclusions too rapidly. If there is any doubt, sweeping or a visual examination with divers will generally resolve it satisfactorily.

6. Echo Sounders; Faults and Fault Finding

Well maintained echo sounders should run for many months without serious faults developing. Most faults develop gradually, over a period of some days at least. The aim should be to detect them in their early stages, so that they can be rectified before the set breaks down.

Method is most important when diagnosing and correcting faults. The prudent surveyor will always diagnose before prescribing a cure. In this diagnosis a great deal can be done using the echo sounding recorder, and the human eye and ear, as the sole testing instruments. An instrument such as the Universal Avometer can be of great use, but it is not absolutely necessary.

The surveyor who has read and digested the preceding sections of this chapter should have little difficulty in keeping a set running well, without outside assistance. The notes which follow are designed to assist him in his task; they may be applied universally, but make no claim to be all embracing.

a. Complete loss of trace on the recorder

If, when the set is switched on, it fails completely to mark the record paper, the procedure outlined in the table opposite will generally isolate the cause.

b. Irregular transmission and echoes

Irregular transmissions and echoes may be caused by the following factors:

(1) Defective or dirty transmitting contacts in the recorder or contactor unit.

(2) A defective gas discharge valve, which is flashing only intermittently. If this is suspected watch the valve; its intermittent operation will generally be obvious. Note that a valve that gives trouble in the fast speed setting may work perfectly well in the slow speed setting.

(3) Defects in the power units or rotary converters. These are not very likely to give trouble.

c. Trace obscured by continuous dark markings

Sometimes an echo trace is completely obscured by continuous dark markings. These can be caused in the following ways:

(1) If the fix push is made permanently, the trace will be blacked out. Foot operated pushes seem more prone to sticking in the 'On' position than those operated by hand.

(2) An unstable amplifier may start to self oscillate, and this will cause the trace to black out. Self oscillation may be caused by:

  (i) too little grid bias; a high setting of the gain control will tend to cause self oscillation in certain circumstances;

  (ii) the H.T. voltage being too high;

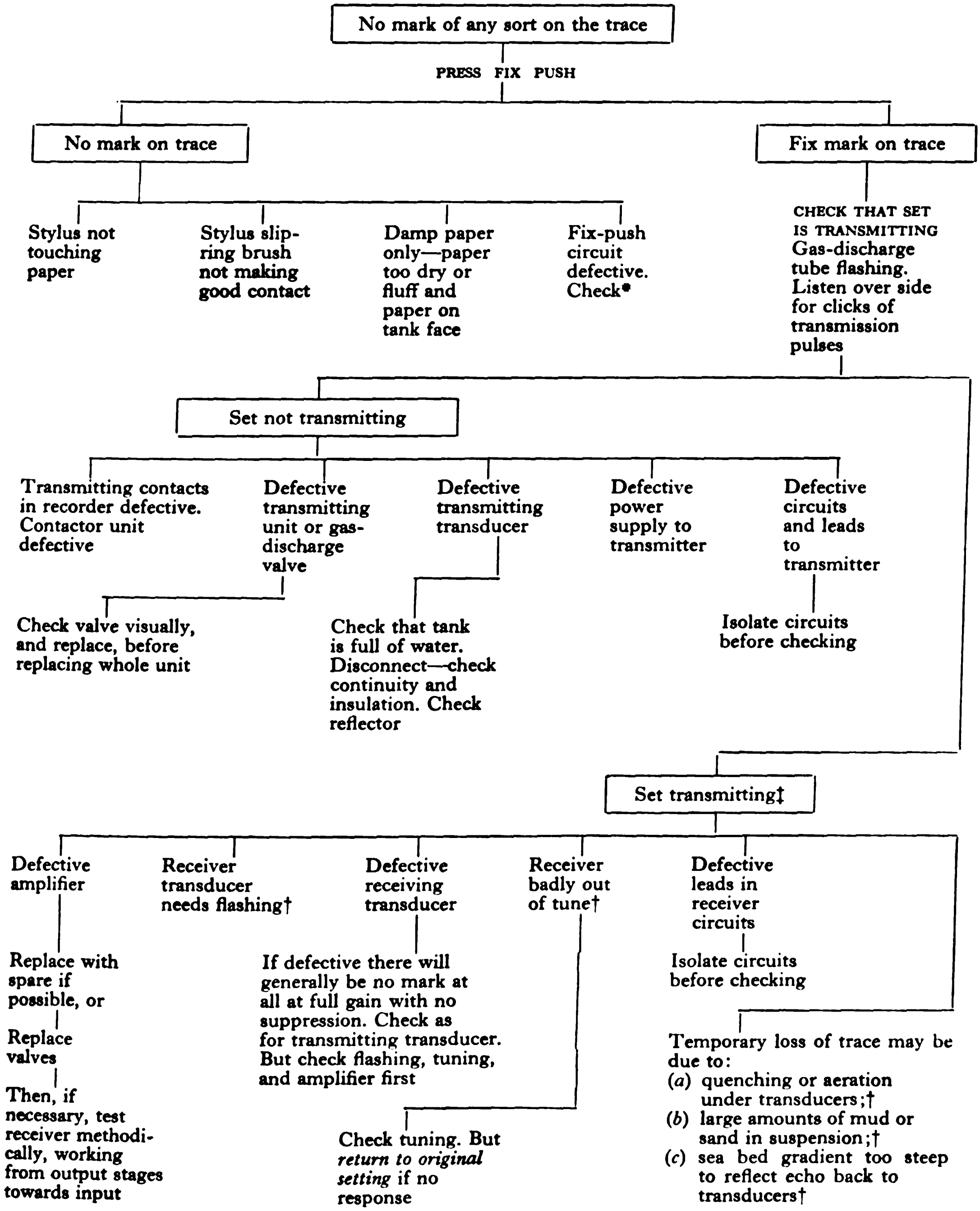
  (iii) an unstable valve or valves; a valve can be unstable in one position in an amplifier and stable in another; if valves are in short supply it may therefore be worth while to change them around;

  (iv) bad earthing of the amplifier chassis, or badly screened leads to, and in, the amplifier;

  (v) defective components in the amplifier.

If the fault lies in the amplifier the points outlined above should be dealt with in the order given. If a spare amplifier is available it should be fitted, so that the defective one may be repaired at leisure.

UNIVERSAL FAULT FINDING TABLE


No mark of any sort on the trace
PRESS FIX PUSH
No mark on trace
Fix mark on trace
Stylus not touching paper
Stylus slip-ring brush not making good contact
Damp paper only—paper too dry or fluff and paper on tank face
Fix-push circuit defective. Check*
CHECK THAT SET IS TRANSMITTING Gas-discharge tube flashing. Listen over side for clicks of transmission pulses
Set not transmitting
Transmitting contacts in recorder defective. Contactor unit defective
Defective transmitting unit or gas-discharge valve
Defective transmitting transducer
Defective power supply to transmitter
Defective circuits and leads to transmitter
Check valve visually, and replace, before replacing whole unit
Check that tank is full of water. Disconnect—check continuity and insulation. Check reflector
Isolate circuits before checking
Set transmitting‡
Defective amplifier
Receiver transducer needs flashing†
Defective receiving transducer
Receiver badly out of tune†
Defective leads in receiver circuits
Replace with spare if possible, or
Replace valves
Then, if necessary, test receiver methodically, working from output stages towards input
If defective there will generally be no mark at all at full gain with no suppression. Check as for transmitting transducer. But check flashing, tuning, and amplifier first
Check tuning. But *return to original setting* if no response
Isolate circuits before checking
Temporary loss of trace may be due to:
(*a*) quenching or aeration under transducers;†
(*b*) large amounts of mud or sand in suspension;†
(*c*) sea bed gradient too steep to reflect echo back to transducers†

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[*] In damp paper sets the fix-push circuit is generally simple and independent of other parts of the set. In dry paper sets this circuit may well be quite complex; very often the fix push signal is amplified in the power amplifier before being applied to the stylus.

[†] These defects will generally only prevent the echo from marking; the transmission line will almost always show.

[‡] At this point it will generally be wise to remove all initial suppression and set the gain fairly high.

d. Recording paper tearing or not running truly

In damp paper sets the recording paper may tear. The cause will generally be one of the following:

(1) Excessive stylus pressure.
(2) A worn or badly set stylus ramp, which allows the stylus to fall on to the paper too soon.
(3) A paper roll or spool which fits too tightly in its cradle; this is most likely to occur with a new roll whose diameter may be too great.
(4) Paper that is too damp. This defect is very difficult to cure, as drying will probably make it too dry.

The paper in dry and damp paper recorders may fail to run truly across the tank face, and have a tendency to run towards one side or the other, becoming rucked and damaged in the process. The fault will generally lie in the paper drive rollers, which must be very carefully adjusted if the paper is to run truly. Since these rollers are usually set by the makers, and are not intended to be adjusted in the field, it is not easy to correct any misalignment that may be present.

7. Portable Echo Sounders

Portable echo sounders are designed to be fitted to any boat or small craft, and to run off a battery. They usually consist of a transducer unit or 'fish', and a recorder, which also houses the transmitting and receiving circuits and power supplies.

The transducer unit may contain one or two transducers, depending on its design. It is important that the insulation of the leads which connect it to the recorder should be as nearly perfect as possible; the receiving circuits are more affected by low insulation than the transmitting circuits. Water and damp salt air must be rigorously excluded from all joints and connections in these leads, which must also be encased in a properly earthed screening sheath. Low insulation and bad screening and earthing probably cause half the troubles which beset portable echo sounders.

The best place to fit the 'fish' of a portable set is amidships, on either side. It should not be fitted too deep, and may be well above the level of the boat's keel, provided it is not screened by the latter and runs in smoothly flowing water when the boat is under way. A fish should never be fitted over the stern of a boat, unless there is no alternative, since in this position it is difficult to handle and secure, and quite likely to be damaged.

8. Leadlines and Sounding Poles

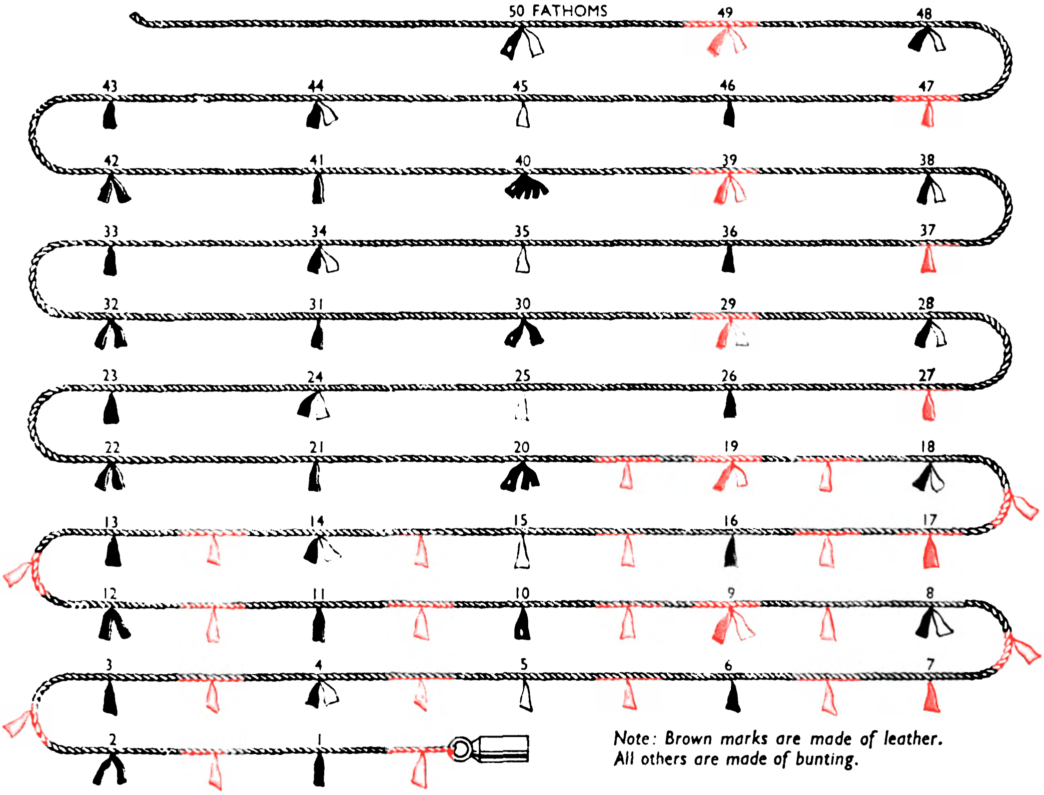
Although most modern hydrographic surveys are carried out using echo sounding equipment, leadlines and sounding poles may still be used in the following circumstances:

(1) When echo sounding equipment is not available, or cannot be fitted into the ship or boat which is to be used for sounding.
(2) As an aid in the classification of possible false echoes, and to check the least depth obtained over a pinnacle rock, coral head or shoal. Whilst the leadline may not always obtain the least water, it will, if the suspected shoal exists, almost always provide the surveyor with incontestable evidence of this fact. Leadlines and sounding poles can be very useful in areas where kelp or weed is growing, or where an extremely soft bottom makes it difficult to determine where liquid water ends and solid bottom starts.
(3) For obtaining bottom samples where more sophisticated methods are not practicable.

a. Leadline markings; calling soundings

Fig. 3–28 shows the system of marking leadlines adopted by the Surveying Service of the Royal Navy. In addition to the markings shown, foot-marks (consisting of small knotted lengths of light line) should be attached for a sufficient length to ensure that a depth of at least 65 feet (reduced) may be measured; e.g., if the maximum rise of the tide is 21 feet, the foot markings must extend to 65 + 21 = 86 feet, or as far as the 14½ fathom mark. It is not likely that a leadsman in a boat will be able to manage a line much longer than about 15 fathoms.

UNIFORM SYSTEM OF MARKING LEAD LINES



Note: Brown marks are made of leather.
All others are made of bunting.

Lines (marked as above) to have in addition one knot inserted at every 1, 2, 4, and 5 feet of each fathom for a sufficient length to ensure that at least 65 feet (reduced) may be measured; e.g. given spring rise 25 feet, 25 + 65 = 90 feet therefore line to be marked in feet to 15 fathoms.

UNIFORM SYSTEM OF CALLING SOUNDINGS

FOR THAT PORTION OF THE LINE WHICH IS MARKED, VIZ.	SOUNDINGS ARE TO BE CALLED	
IN FATHOMS AND FEET	TO THE NEAREST FOOT	"FIVE THREE, FIVE TWO, FIVE ONE. FIVE FATHOMS, FOUR FIVE, ETC., ETC."
IN FATHOMS AND HALF FATHOMS	TO THE NEAREST ESTIMATED HALF FATHOM	NINETEEN FATHOMS, EIGHTEEN THREE, EIGHTEEN FATHOMS, ETC.
IN FATHOMS ONLY (20 TO 50 FMS)	TO THE NEAREST ESTIMATED FATHOM	THIRTY FATHOMS, THIRTY ONE FATHOMS, ETC.

Note. The only exception to the above is that 9 and 11 fathoms are to be called "Deep Nine" and "Deep Eleven", the word fathom being omitted, in order to distinguish them from 5 and 7 fathoms, thus:—"Deep nine one, Deep eleven, Deep eleven three."

Fig. 3–28

The uniform system of calling soundings is also shown on Fig. 3–28. Great care should be taken to ensure that phonetic mistakes do not occur between the leadsman and the recorder; every sounding called should always be repeated by the recorder, who must take particular care to differentiate between five and nine, and seven and eleven.

b. Preparation, marking and checking of leadlines

Ordinary rope leadlines are not recommended for surveying purposes, since they shrink and stretch in a random manner whilst being used. If they are used they must be checked against a stable standard at frequent intervals (small plates may be set into the deck of a ship at fathom intervals to provide this standard), and re-marked if necessary.

If a wire heart made of galvanised wire about ⅛ inch in diameter, or better still of flexible phosphor bronze, is laid into a leadline, its stability is much improved. Wire-hearted leadlines are very unlikely to stretch by more than one or two per cent whilst in use. However, if they are not made properly the rope may well shrink, causing the wire heart to kink and come out of its correct lay; if this happens, the leadline will be shorter than it should be, and will almost certainly cut the leadsman's hands.

Before inserting the wire heart, a leadline should be thoroughly stretched. If unproofed it may be towed over the stern of a ship for about 24 hours, and then dried under considerable tension, the process being repeated twice; or stretched between two stanchions, thoroughly wetted, and loaded with weights on the bight for anything up to two weeks or so. Proofed or waxed rope is resistant to moisture, and can therefore only be stretched by loading it with weights on the bight. If weights are used, the slack in the rope should be taken up from time to time; the end point is reached when no further stretching takes place in 24 hours. Judgement is required in selecting the correct weight to use; too little will prolong the stretching period unduly; too much will probably strain the rope as well as stretching it, and damage its structure.

When inserting the heart, the aim should be to insert the shortest possible length of wire into a given length of rope, without introducing too much 'bunching' of the rope strands. Both ends of the wire must be firmly secured inside the rope; an eyesplice in which the strands of wire are tucked alongside the rope strands, and then served over, will generally do this.

Leadlines should be wet when they are marked, and under their working tension. The fathom and half fathom marks should be seized to the line, and not tucked under a strand, as this will tend to cause the wire heart to break out. The seizings must ensure that the marks cannot slide up or down the line as it is being used.

Wire hearted leadlines should be checked against a stable standard once a day whilst they are in use.

Although it has not been used in the past, composite line, consisting of braided hemp and non-ferrous wire, might well be very suitable for leadlines. The surveyor who is going to carry out a lot of leadline sounding is advised to experiment with it.

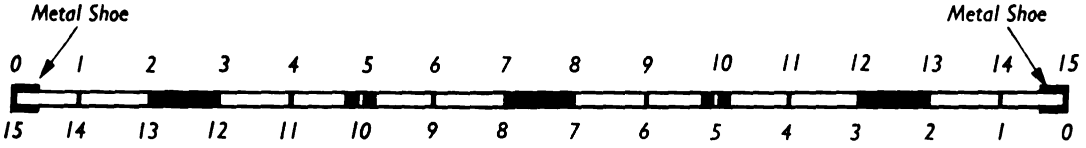
c. Sounding poles

Where the depth of water does not exceed 10 or 12 feet over a fairly large area, a sounding pole is more convenient to use than a leadline.

Fig. 3–29 shows a typical sounding pole; its design closely resembles that of a pole used by the U.S. Coast and Geodetic Survey. It is made from a boathook stave or other suitable length of timber about 1½ inches in diameter, and fitted with a metal shoe at either end. These shoes may be weighted, if desired, so that the pole does not have too much positive buoyancy; they may also be fitted with broad sole plates if the bottom is very soft.

Note that the markings are symmetrical about the centre of the pole, so that either end may be used to obtain a sounding. In use the pole should be turned end for end between soundings. and not lifted completely out of the water.

SOUNDING POLE



This Pole should be painted White, with Black markings

Fig. 3–29

9. Sounding machines

Sounding machines were used, before the invention of the echo sounder, to measure depths too great for the leadline. Today they are seldom used except to obtain fairly deep bottom samples from a boat, and in sweeping operations. They are sometimes modified and used as simple hand operated winches.

The 400-fathom Lucas sounding machine described below is typical of most that may be encountered.

a. The 400-fathom Lucas sounding machine

Fig. 3–30 shows a 400-fathom Lucas sounding machine. The drum *A* holds about 400 fathoms of 20½ gauge galvanised piano wire, which weighs 15 lb per 1,000 fathoms and has a breaking strain, when new, of about 240 lb. This wire corrodes after a little use, and loses much of its strength; it also tends to kink when not under tension, and then breaks very easily.

The drum may be turned by the handle *H*, acting through the train of gear wheels; if the locking lever *J* is lifted, the handle spindle, which also carries the upper gear-wheel, may be moved to the left, and locked again in its new position; this disengages the upper gear-wheel from the idler, and allows the drum to rotate independently.

Two curved arms *C*, which carry the measuring wheel *F* and the indicator *G*, are pivoted near their lower ends, and supported by the springs *D*. The tension of these springs may be adjusted by two knurled knobs, one of which is shown at *E*; this tension should be enough to hold the pivoted arm assembly firmly in the up position until the weight of a lead is added to that of *F* and G.

A brake band *B* bears on the flanges of the drum *A*. It is anchored at the back of the machine. Just below the anchorage a hand clamping screw, which is hidden by the frame of the machine in Fig. 3–30, bears on the brake band. The free end of the brake band is attached to the bottom of the lever system formed by the curved arms *C*, so that the tension of the springs normally holds the brake in the 'On' position; when the weight of a lead is added to that of *F* and *G*, the arms will pivot outwards, releasing the brake; provided the hand clamping screw is eased back, the drum will then be free to revolve. When the lead strikes the bottom, the springs should automatically apply the brake and prevent the machine from overrunning.

A guide arm *I* is fitted so that the wire may be wound evenly on to the drum when heaving in. The measuring wheel and indicator may be detached as one unit; indicators usually measure 0 to 200 fathoms in fathoms, or 0 to 20 fathoms in fathoms and feet.

Referring to the figure, the wire is led from the bottom of the drum *A*, between the forks of the guide arm, and then takes just over one complete turn round the measuring wheel in a clockwise direction; it is important to check that this complete turn has been taken, if the machine is to be used for sounding, as without it slip may well take place, causing the indicator to under-read. If the machine is not to be used for sounding, it will

LUCAS SOUNDING MACHINE (400 FATHOMS)

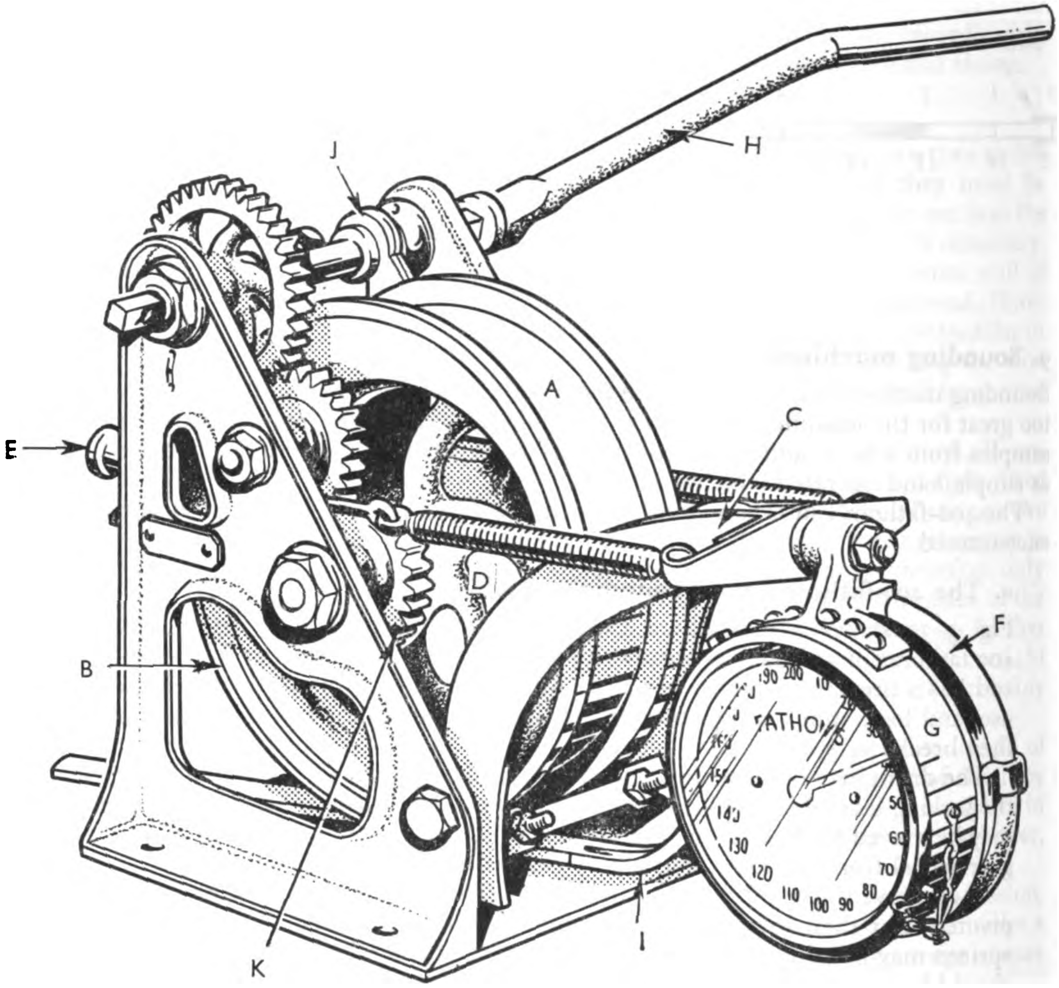


Fig. 3–30

probably be better to use the measuring wheel as a simple leading block. Before it is attached to the sounding lead, the wire should be hearted up inside a few feet of hemp or sisal stray line.

b. Sounding by machine

To take a sounding the lead should be lowered to the water-line, and the friction driven indicator pointer set to zero; this indicator should be reasonably tight on its spindle. The hand clamp screw should be tightened before the hand drive is unclutched; when all is ready, it may be eased off, and the lead will descend.

It is important that the speed of the descending lead should not be allowed to exceed 100 to 150 fathoms per minute; if in doubt it is better to lower it too slowly rather than too fast. If the speed of descent is too great, particularly to start with, then as it is reduced by the friction of the wire in the water, the inertia of the drum will cause it to overrun; turns of wire will be thrown off, and they will almost certainly snarl up. The speed of descent may be controlled by adjusting the tension on the springs, working the hand clamping screw, or better still, by applying a pad of canvas by hand to the top of the revolving drum.

As the lead strikes the bottom, the brake mechanism should stop the drum automatically. The depth should be read off the indicator dial the moment the curved arms fly up.

In practice, snarls are bound to occur from time to time. A stopper should always be ready to hand so that the weight of the lead may be taken off the machine whilst they are being cleared. It will be wise to carry several spare leads in the sounding boat.

For work in less than 100 fathoms, an 11 lb lead should be heavy enough. In greater depths it may be necessary to increase this weight to 22 or 28 lb. The aim should be to use as little lead as possible, so long as the speed of descent is reasonable, and the indication of the lead striking the bottom is clear.

When using sounding machines, care must be taken to prevent the wire from growing under the boat or ship, or fouling the screws or rudder. Piano wire breaks easily, but can bite deeply into a propeller shaft if it winds round it. The machine should generally be worked from the windward side of a vessel. Allowances may have to be made for tidal stream, if the surface and sub-surface streams differ. It is very unlikely that a wire which enters the water at a certain angle will maintain that same angle all the way to the lead; wire soundings corrected for the slope of the wire as it enters the water should therefore be treated with caution. Even if a wire enters the water vertically, there is still no certainty that it remains vertical all the way to the bottom, unless the water is comparatively shallow (less than about 10 fathoms) and the tidal streams are very weak; for this reason no deep wire sounding can be regarded as being completely free from error.

c. The 1,000-fathom Lucas sounding machine

Fig. 3–31 shows a 1,000-fathom Lucas sounding machine. It is larger and simpler than the 400-fathom machine described in a above, and may be more convenient to use in certain circumstances; its method of operation is similar to that of the smaller machine.

It consists of the following parts:

A. The main drum, which holds about 1,000 fathoms of 20½ gauge galvanised piano wire.

B. The brake band; its upper end is anchored and its lower end attached to the bottom of the brake lever mechanism.

C and *D.* The brake lever and springs.

E. The clamp handwheel.

F. The measuring wheel.

G. The indicator, which is graduated in fathoms up to 1,000 fathoms; it may be detached from the measuring wheel.

H. The handles, which fit directly on to the spindle of the drum.

I. The wire guide, which also serves as a support for the measuring wheel and indicator.

d. Calibrating a sounding machine

If the circumference of the measuring wheel, or the diameter of the sounding wire differ from the values adopted by the designers of a sounding machine, indicated depths may contain errors. The calibration procedure outlined below should detect these errors if they exist, and also ensure that there is no slip between the wire and the measuring wheel under working counditions. Measuring wheels should be calibrated as soon as they are received, at approximately yearly intervals thereafter, and if there is any reason to suspect their accuracy.

LUCAS SOUNDING MACHINE (1000 FATHOMS)

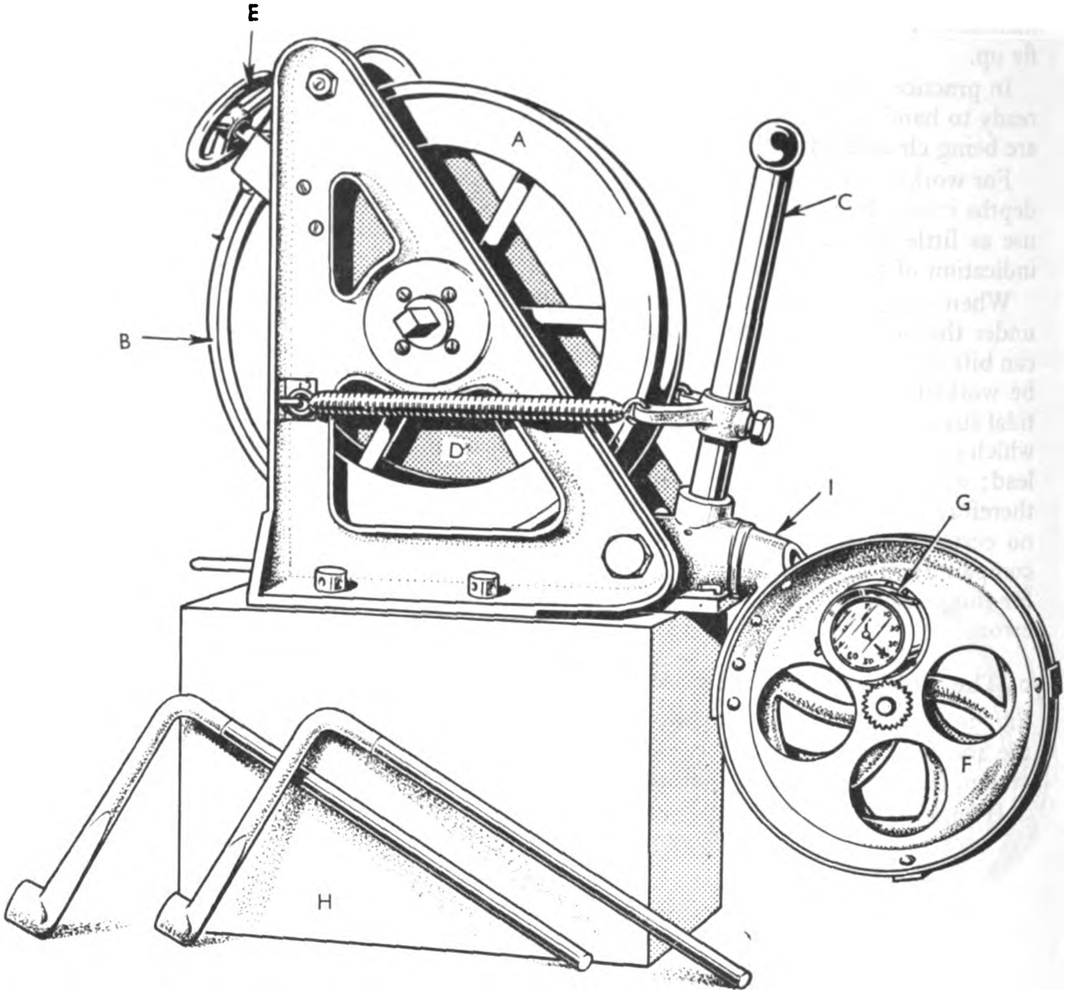


Fig. 3–31

Referring to Fig. 3–32, the calibrating procedure is as follows:

(1) Set up two ranging poles, or other convenient marks, at a known distance apart. This distance should be measured with a steel tape; it may be anything between about 40 yards (for 20-fathom measuring wheels) and 200 yards (for less sensitive measuring wheels).

(2) Set up the Lucas machine, and reeve the sounding wire as indicated in the diagram. An assistant should apply tension to the far leading block so that the lead is kept nicely off the ground without fouling the block.

(3) With the assistant standing just beyond the near ranging pole, set the pointer on the indicating dial to zero. Then adjust the mark on the wire so that it is alongside the pole.

(4) Instruct the assistant to walk slowly away, until the mark on the wire comes level with the far ranging pole. As he does so, pay out sounding wire, using the handles

to control it, and adjust the tension as necessary to keep the lead nicely off the ground.

(5) Read the dial when the mark reaches the far ranging pole. The indicated depth ought to agree with the measured distance.

(6) Then wind the assistant in again, until the mark is alongside the near pole once more. The dial ought to read zero.

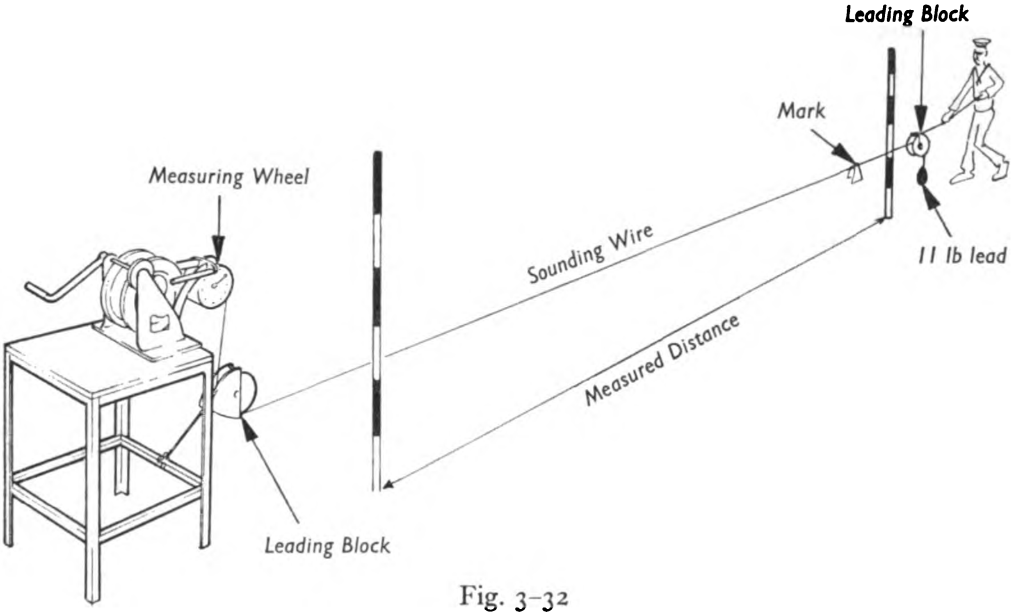


Fig. 3-32

Repeat these operations about five times, and mean the results. The fact that the wire hangs in a catenary between the two leading blocks will not have a measurable effect on the calibration, provided the unsupported wire is not longer than 25 fathoms. If the measured distance is greater than this, the wire should be supported by a light trestle, or better still, by the finger of an assistant every 25 fathoms or so.

Errors should not exceed one half per cent of the measured distance; if they do, corrections must be applied to all depths obtained with the equipment. If the wire is slipping round the measuring wheel, there will probably be quite large discrepancies between individual measurements; an increase in the tension will probably correct this fault, provided the measuring wheel itself is in good condition and quite free to revolve in its bearings.

The tension applied to the wire when calibrating must, of course, be equal to that which it is intended to use whilst sounding.

Part 2 Methods of Fixing; Instruments

10. Introduction

The surveyor, sounding in a ship or boat, can fix his position in many ways. He may observe angles visually either in the vessel itself (resection), or from known postions ashore or afloat (intersection); he may measure distances (trilateration), or a combination of angles and distances (traversing or subtense methods); or he may obtain his position by electronic means, measuring time intervals and converting these into distances which may be plotted in the same way as those obtained by mechanical or optical methods.

When choosing a method for fixing, the following points should be considered:

(1) Whatever method is chosen, the required position will be at the intersection of two or more position lines. These position lines must always intersect at a reasonable angle, e.g., two position lines should interesect at an angle as near to 90° as possible, three position lines at 60°, and so on. It very often happens that, out of three position lines available, two intersect at a small angle, whilst the third cuts both of them very nearly at right angles, giving a strong fix. If all the position lines intersect at small angles, then small errors of observation will lead to large errors in the plotted position. In some cases the position lines forming a fix will actually be drawn on the plotting sheet or board, and the strength of the fix will be apparent at a glance. Where they are not (as, for instance, when using a station pointer for plotting) it is important that the surveyor should train himself to visualise them mentally.

(2) Other things being equal, a fixing method which enables the surveyor himself to plot his position quickly and easily will be better than one which, whilst perhaps being extremely accurate, fails to provide him with up-to-date knowledge of his position. For example, when boat sounding, it will usually be better to obtain sextant fixes in the boat than intersecting theodolite observations from known points ashore.

(3) The surveyor must always find out, and note (at least mentally), the probable random and systematic errors of any method of fixing which he may use. It is comparatively simple to calibrate most systems of visual or mechanical fixing. It is usually far more difficult to calibrate an electronic system, since the speed of propagation of radio waves in air (a quantity which is not easy to evaluate) is nearly always involved. The temptation to assume that the answer produced by the 'black box' is always right must be strongly resisted; in nine cases out of 10 it will be wrong, and corrections will have to be applied.

(4) There is no point in using a fixing system that is far more accurate than the work in hand requires. The prudent surveyor need only be as accurate as the scale of his plot requires, but he will always know just how accurate he is, and will be able to quote systematic and random errors if his methods are ever held in question. However, if there is any doubt as to the degree of accuracy required in any particular task, the surveyor should make sure that he errs, if at all, on the safe side.

In the sections which follow, various methods of fixing, and the instruments necessary to them, are described. Whilst all these methods have been used successfully in the field, no claim can be made that they provide the only sensible ways of tackling a particular problem. If these descriptions stimulate the surveyor into devising new, more accurate, and simpler methods, so much the better.

11. Fixing with Sextant and Station Pointer

The sounding sextant is described, and the use of it discussed, in Volume 1, Chapter 4, Part 2. The problem of obtaining a position by resection is dealt with in Volume 1, Chapter 5, Section 18. In what follows it is assumed that the surveyor has read and assimilated these relevant parts of Volume 1.

a. Choosing the angles to be observed

Very often the young surveyor, knowing very well the requirements of a good fix, will be at a loss to decide which objects to choose. It may well be that two or three fixes will give equally good results at a particular point: it will be almost certain, however, that one of these will be better than the others for the purpose he has in mind. The problem is how to choose the right one. Experience is the only certain guide, but the points outlined below may be helpful:

(1) Choose a fix that will remain strong and suitable for as long as possible. It is essential to visualise the position lines; there will be three of them, one for each of the angles actually observed, and a third corresponding to the sum, or in some cases the difference, of these two angles.

(2) If the centre object of the fix is easy to pick up in a sextant, so much the better. If this is not possible each observer should be able to pick up one out of his pair of objects fairly easily. Never choose three indistinct objects for a fix, except as a last resort.

(3) If one of the angles of the fix changes slowly, and the other rapidly, as the vessel proceeds, the fix is almost certain to be a good one, from all points of view.*

(4) Unless it is absolutely necessary, do not change both angles of a fix at the same time. A process similar to leap frogging has much to recommend it: one angle is changed as the fix tends to become unsuitable, and in due course the other angle is changed, the observers leap frogging over each other.

(5) When conditions are difficult, it may be prudent for the surveyor to allocate the easier of two angles to his assistant, if necessary by exchanging angles with him from time to time. He may then rely on his assistant's angle always being obtainable, and he himself may combine with it an angle observed to one of perhaps two or three other marks, as the opportunity occurs.

(6) In a well managed sounding vessel, the surveyor will always know what objects he intends to use for fixing at least two fixes ahead, and will inform his assistant in good time of any impending changes. It should never be necessary for the assistant to have to report that his angle has become too large to measure, or that his outside mark has disappeared behind a headland, just as a fix is about to be taken.

b. A practical test for a good sextant fix

A good sextant fix has three attributes:

(1) It will be easy to plot, being firm and rigid.

(2) At least two out of its three position lines will cut at a good angle.

(3) The measured angles will both be sensitive. That is to say a small movement towards or away from the centres of their corresponding circles of position will alter the angles appreciably.

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* Care must, of course, be taken to ensure that the slowly changing angle does not do so because it is too small.

Attribute (1) automatically follows from (2) and (3), both of which must be satisfied if the fix is to be good. Sensitivity depends on the size of the angle and the disposition of the marks relative to the observer. Small angles may be very sensitive, or quite insensitive; large angles will usually be sensitive.

If there is any doubt about the suitability of a particular fix, the following test, which may be applied in the field, will always resolve it quickly and simply, without recourse to theory.

(1) Set the observed angles on the station pointer, and plot the position in the usual way.

(2) Move the centre of the station pointer slightly from the plotted position, keeping the left and centre arms of the instrument on their respective points. The right arm should move rapidly away from its point, if the fix is good.

(3) Repeat (2) above, keeping the right angle on. The left arm should move rapidly away from its point.

Both parts of the test must be satisfied for the fix to be a good one.

c. Reducing the effect of errors of observation in a sextant fix

In Fig. 3-33 the surveyor and his assistant are in a moving boat at *D*. They wish to fix their position, using two sextants and the marks *A*, *B* and *C*. It can be seen from the figure that the fix is extremely strong. It can also be seen that this strength depends very much on the position line *ADC*, corresponding to the angle *z*, which cuts both the other position lines at an angle close to 90°. The position lines *ABD*, and *CBD*, corresponding to the angles *x* and *y* respectively, do not cut at a particularly good angle; this angle will become smaller as *D* approaches *B*.

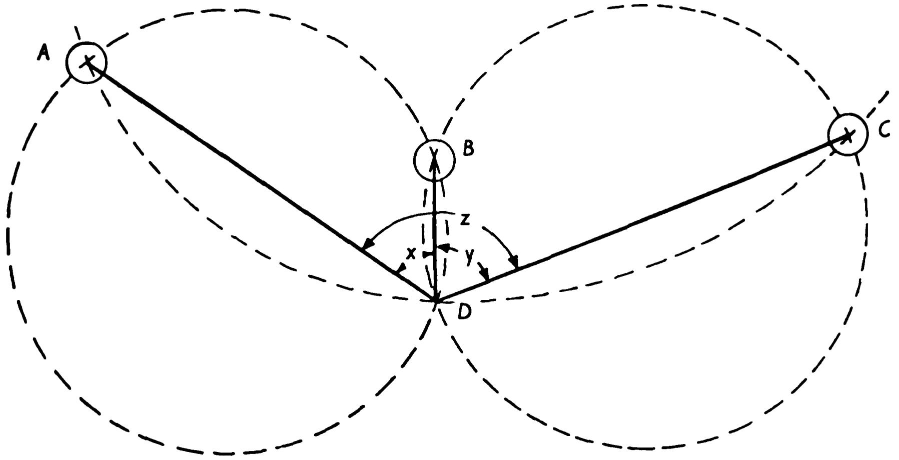

Fig. 3-33

The surveyor, well aware that the fix is extremely strong, will probably be tempted to measure the angles *x* and *y* in the normal way. This would be perfectly satisfactory if the angles were taken at the same instant, from the same point, and were without error. However, the boat is moving, and the observers cannot stand in exactly the same point, or observe at precisely the same instant. Their measurements of *x* and *y* are likely to contain comparatively large errors, since *B* is close; in the plotting process these will automatically be injected into the angle *z*, upon which the strength of the fix mainly depends, and which is extremely sensitive. The result will be an excellent fix in the wrong place.

The remedy is to observe the angle z directly, and either x or y.

If this cannot be done it is important to reduce the errors of observation of x and y as much as possible. The observers must stand as close together as possible, and take great care to observe at the same moment.

The situation described above arises when the central object is much closer to the observers than either of the two outside objects. If the position lines forming the fix are visualised the surveyor should be able to assess whether or not he must take these special precautions whilst observing.

As a general rule it may be stated that the angle corresponding to the best position line out of the three available (in this case z) should always be observed directly.

d. Plotting a sextant fix

Various instruments may be used to plot a sextant fix. They are described below:

(i) The station pointer. Fig. 3–34 shows a station pointer suitable for boat sounding. The diameter of its graduated circle is about six inches. Larger sizes, with circles of eight inches and 12 inches diameter, are also available; they are more accurate than the one shown, but the 12-inch model is very heavy and cumbersome.

Referring to the figure, the fixed leg is firmly attached to the graduated circle. One edge (the upper one in the diagram) is bevelled, and forms the zero index of the instrument. This edge must coincide with the zero of the graduated circle, which is graduated from 0° to 180° in both directions, and its continuation must pass through the centre of the plotting nick. Before using a station pointer it will always be prudent to check that these conditions are satisfied, and that the leg itself is perfectly straight.

A 6-INCH STATION-POINTER

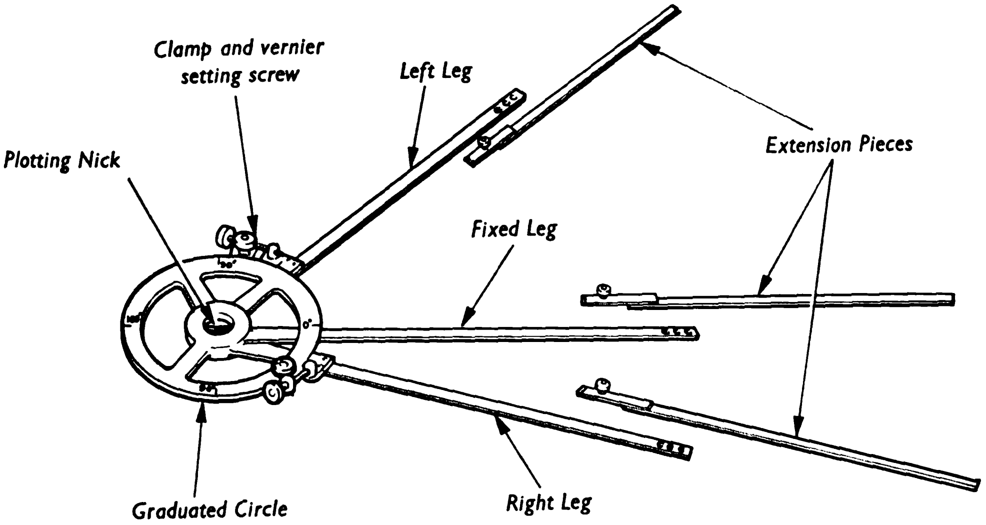

Fig. 3–34

The left and right legs are similar in construction. They may be rotated about the graduated circle, or clamped and set to the nearest minute of arc with their clamps and vernier setting screws. Their inside edges are bevelled, and form the plotting surfaces. These edges must both, when produced, pass through the centre of the plotting nick. They must also be aligned with the indices of the vernier or micrometer setting scales; an adjustment is provided on the scales so that this can be done. The legs must be straight, and the clamping and setting arrangements must be free from backlash.

Clearly, only one of the movable legs (in this case the left leg) can be set to an angle of 0°. The other will foul the back of the fixed leg when it makes a small angle, usually about 5°, with the latter. Three extension pieces are usually provided, to extend the range of the instrument. These extensions are hand fitted to their individual main legs; they must never be interchanged between legs or instruments.

To plot a fix with a station pointer, proceed as follows:

(1) Set the observed angles on the left and right legs respectively, to the nearest minute of arc.

(2) Grasp the instrument by the graduated circle and the fixed leg, and place it on the board with the plotting nick in the vessel's estimated position, and the bevelled edge of the fixed leg passing through the plotted position of the central object. The instrument should never be held by the outer legs, as this may well alter their settings, or bend them.

(3) Make small adjustments to bring all three legs 'on' together, and mark the vessel's position, which will be in the centre of the plotting nick.

Practice, and more practice, is the only way to achieve facility in plotting a station pointer fix. It should be remembered, however, that a good fix will always be much easier to plot than a bad one.

(*a*) THE STATION POINTER CORRECTOR; CHECKING A STATION POINTER IN THE FIELD. Station pointer correctors may be constructed on metal or stable plastic sheets. Angles should be protracted at 10° intervals using chords. The radii of the protracted points must be large enough to embrace the span of the largest station pointer carried; points should also be plotted at smaller radii, so that smaller instruments can be calibrated conveniently. Corrector diagrams drawn on paper should not be used by the surveyor, as they can distort very appreciably.

Station pointers should be checked on a station pointer corrector at the start of each survey and if there is any reason to suspect their accuracy.

The following checks may be made in the field:

(1) Draw a straight line, and set the station pointer against it with each leg in turn set to 180°; repeat with the legs set simultaneously to 90°.

(2) Both legs will have housed positions, when they are hard up (but not too hard), against the centre leg. The angular value of these positions should be noted when an instrument is adjusted, for future reference in the field.

(3) The 'forts' on a sounding board often form a rectangular grid, which may be used for checking station pointers. Too much reliance should not be placed on this test, however, particularly if it is in conflict with that described in (1) above, since sounding boards can distort.

A station pointer may have index error, centring error, or bent legs. Index error can be removed; centring error must be applied to individual angles; bent legs should be straightened.

(ii) Three arm protractors. Three arm protractors are really simplified and less expensive versions of the station pointer described above. Very often they are made of transparent plastic; the circle graduations are usually in degrees or half degrees.

They are convenient to use when the fixing marks are close to the observer, as plotted on his field board. However, they are liable to distort, and in many cases parallax errors must be guarded against when using them, since their index lines do not usually lie flush on the plotting surface. Sometimes it is difficult to ensure that the position plotted lies exactly in the centre of the central plotting hole, since the surveyor cannot see exactly where he is placing his pencil point as he plots.

(iii) The Cust protractor. A Cust protractor is a sheet of transparent plastic with an angular scale and datum line engraved on it, and a central hole. The angles of a fix are protracted in pencil upon the engraved side of the sheet. This is then turned over, and the fix is plotted in the usual way; the central hole is usually just large enough to take the point of a sharp pencil. Since the protracted pencil lines are on the engraved side of the material, and are in contact with the plotting surface as the fix is plotted, parallax errors are avoided. However, because the sheet is turned over before plotting, the angles must be reversed, left for right and right for left, as they are protracted.

Cust protractors are very useful when the lengths of the rays (on the plotting board) are short; if used carefully they are inherently more accurate than the three arm protractors described above. They can also be very useful if more than two angles have been taken at a fix, since there is no limit to the number of rays that may be plotted on them. If desired, several rays may be plotted on a sheet of tracing paper in the way described in Volume 1, Chapter 5, Section **18c.**

e. Observing check angles when sounding

When actually sounding the surveyor will not have the time to observe check angles; nor will he have the means to plot them quickly and accurately. However, they should be observed from time to time, with the vessel stationary, and particularly when new marks are being used for the first time. A check angle that agrees with the main fix will give the surveyor confidence that his identification of marks is correct. More important perhaps, it will guard against the misplotting of sounding marks, an event which occurs from time to time even in the most well regulated surveys. If a check angle fails to agree with the main fix, none of the marks common to it and the main fix should be used until the discrepancy has been resolved.

It must be remembered that to be of any use a check angle must be sensitive. (*See* Section **11b** above.)

12. Fixed Angle Plots

The construction of lattices of constant subtended angle is described in Volume 1, Chapter 6, Section **18.** These lattices are generally known as fixed angle plots, since the position circles associated with certain 'fixed' angles are plotted on the sounding board by the surveyor, who then interpolates his observed positions between them by eye.

Fixed angle plots have the following advantages over the station pointer method of fixing:

(1) On large scales, where the sounding marks are widely separated on the scale of the survey, they make for compactness, since there is no need to show the marks on the sounding board.

(2) Fixes may be plotted quickly and easily, provided linear interpolation between the plotted arcs is permissible (*see* Volume 1). The vessel's position between fixes can also be monitored much more easily than with the station pointer method of fixing.

(3) A common centre object is not necessary to obtain a fix. Therefore the surveyor has more choice in the selection of suitable fixes.

(4) They can be very useful when routine resurveys of the same area are regularly carried out on a fairly large scale.

Against these attributes must be set the following disadvantages:

(1) Considerable labour is required to design, calculate and construct them, particularly on small scales.

(2) There will be a lack of flexibility in the choice of marks. The surveyor can use only those pairs of objects whose arcs have been pre-plotted. This may well be inconvenient if the marks become obscured, or in limited visibility.

(3) If, to overcome this defect, a large number of families of arcs are pre-plotted, the sounding board may become very confusing.

Experience indicates that fixed angle plots will be most useful to the surveyor when he is carrying out an examination of a small area on a large scale, or constantly resurveying the same area, again on a fairly large scale. They can also be useful in avoiding the errors of plotting which are otherwise present if long extension legs are used on station pointers. For example, suppose that an angle to objects three feet away on the scale of the plot can be observed to the nearest minute of arc; using station pointers the surveyor will be lucky if he can plot this angle to the nearest five minutes or so, as the long extension legs will be bound to introduce errors of flexure. A fixed angle plot will avoid the use of the station pointer, and retain the accuracy of the sextant observations.

13. Fixing with Theodolites

This method is not recommended for general sounding work. It should only be used on very large scales, and even then is not usually as good as the subtense methods referred to below. It can be extremely accurate, but has one major deficiency from the hydrographic surveyor's point of view: the surveyor cannot plot his fixes as the sounding is taking place, and therefore cannot control the movement of his vessel to the best advantage.

The method is as follows:

Two theodolites, set up ashore at known positions, intersect the mast or an upright boathook stave on the sounding craft, using suitable zeros. Timing of fixes is co-ordinated by radio, or by visual signal between the boat and the theodolite observers. The angles at each fix are recorded at the shore stations, and the numbers of fixes are checked between the observers and the boat after each line. To guard against gross errors the theodolites should intersect their zeros before and after each line. It is usually necessary to set up transits ashore, in order that the boat may be kept on the line whilst sounding. Sometimes it is preferable to run the lines on one of the theodolites, and to move it for each line, or to 'star' round it; in these cases the boat will manoeuvre so as to keep this theodolite's angle as steady as possible whilst running a line, the observer signalling as necessary to keep it on his vertical wire.

Sounding must be interrupted from time to time, so that the fixes may be plotted. Plotting may be carried out with a station pointer.

14. Fixing by Subtense Methods

Subtense methods are very suitable for use on large scales. Since only one angle is measured in the sounding boat, errors of parallax* are avoided. Transits must be set up ashore to guide the boat along each sounding line, and to provide one of the position lines for each fix. The subtended angle itself may be measured in the vertical or the horizontal plane, in several ways. The surveyor should always ensure that his angles are in fact measured in one or other of these two planes; if he cannot do so then he must apply appropriate corrections before plotting. These corrections are discussed in detail in Volume 1, Chapters 3 and 4.

Many variations are possible using subtense methods. The descriptions below are not all embracing, but will give some idea of what can be done.

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* In this case the parallax would be caused by the inability of the observers to stand in exactly the same place.

a. Fixing by transit and large cut-off angle

Fig. 3–35 represents part of a sounding board prepared for fixing by transit and large cut-off angle.

The main sounding marks *A*, *B* and *C*, have been plotted, and the base lines subdivided into suitable intervals. The points *a*, *b*, *c*, etc., should be marked on the ground with pegs or paint. To establish the transit *cc'* the surveyor's assistant sets the angle θ on his sextant, stands over *c*, zeros on *A*, and directs a man with a portable back mark to place it at *c'*. Ranging poles or boathook staves may be used for the marks at *c* and *c'*. It is important to select a good zero when shooting up the back mark and to centre the sextant very carefully over the front mark. The transit must be sensitive; normally the distance *xc* should not be more than three times the distance *cc'*.

The sensitivity of a transit may be measured in the field in the following way:

(1) With the boat at the outer end of the transit, steam very slowly in towards it, keeping it 'on'.

(2) Move from side to side in the boat, and see whether the transit alters. If it is

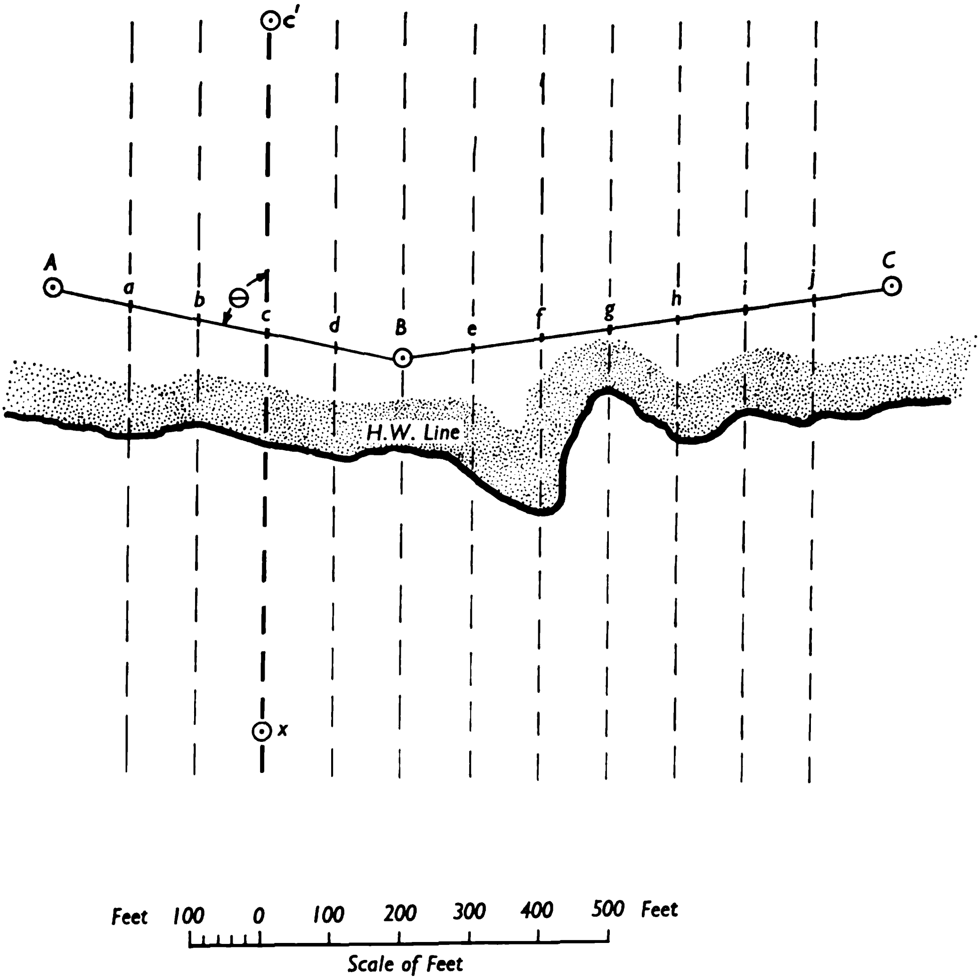

Fig. 3–35

sensitive it will do so, and the smallest lateral movement that can be detected will be an indication of its sensitivity.

The surveyor in the boat sounds along the pecked lines, directing his assistant ashore to move the transit marks as each line is completed. It is easier to run in towards the transit marks, but there is no reason why back transits should not be used once proficiency has been gained. (*See* Section **25g** of this chapter.)

At *x* the surveyor knows that he is on the transit *cc'*. If he measures a sextant angle between *A* and *B*, or *A* and *C* (the larger this angle is the better), he can plot his position on the transit line with station pointers. Care is necessary when selecting the objects for the cut-off angle; for instance, at *x* an angle measured between *B* and *C* would not provide a firm fix, since its position line cuts the transit at a small angle.

The method is extremely flexible. Additional lines can be run, merely by setting up intermediate transits; and the surveyor has a wide choice of angles to measure in the boat. There is no reason why some of the intermediate points (for instance *b* and *d*) should not be marked temporarily to provide a convenient fix close inshore.

b. Fixing by transit and small cut-off angle

This method has been much used in the past, and produces very reasonable results. It is, however, inherently less accurate than that described in a above, and not so flexible.

Referring to Fig. 3–35, the main sounding marks *A*, *B* and *C*, are not necessary. The surveyor sets up a series of transits ashore similar to *cc'*, and plots them on his board. As each transit is run, a small subtense base is set up at the front mark. This may be either horizontal or vertical; a 10-foot pole may be used if the sounding lines are short. The relatively small subtended angle is measured to obtain distances from the front mark. This angle will not be very sensitive, and will not be suitable for plotting by station pointer. It is usual to prepare in advance a table which converts subtended angle into distance.

Care must always be taken to ensure that the subtense base provides a firm fix at the outer ends of the sounding lines. As a general rule the boat's distance from the front mark should not be greater than 10 times the length of the base.

15. Fixing by Compass, Rangefinder, and Horizon Dip

Where a fairly low standard of accuracy is acceptable, or other more accurate methods cannot be used, fixing may be carried out by combining a compass bearing with a distance obtained by rangefinder or horizon dip.

The measurement of distance by angle or depression below a sea horizon is discussed in Volume 1, Chapter 3, Section 24. Distance measurement by rangefinder is discussed in Section 26 of the same chapter. Compass bearings are obtained in the usual way, which is described in all manuals of navigation. The surveyor should remember, however, that gyro compasses do not like frequent and violent alterations of course or speed, and react by giving erroneous readings; the maximum gyro error from this cause is likely to be present about 20 minutes after the alteration of course or speed has been made.

16. Fixing by Taut Wire

The measurement of distance with taut wire is described in Volume 1, Chapter 3, Sections 10 to 16.

Before the advent of electronic methods of fixing, taut wire was most useful to the surveyor who wanted to sound out of sight of land. It provided excellent position lines for fixing beacons and other floating marks, and was used on occasions actually to provide one position line whilst sounding.

Nowadays it is not used nearly so much, but nevertheless can still be most useful on occasions. The examples of its use set out below may stimulate the surveyor into devising his own methods of using it to advantage.

a. Fixing with taut wire whilst sounding

If taut wire is run whilst a vessel is sounding, it will provide excellent position lines at right angles to the direction of progress, as and when they are required. These may be combined with position lines obtained in one of several other ways, for example by sextant, gyro, or astronomical observation, to give a fix. Taut wire has very few vices, if it is properly calibrated and carefully used, and the position lines obtained from it may always be relied on.

b. The use of taut wire as a check on Decca

Sometimes it is necessary to sound outside the limits of 'Decca Daylight'* whilst fixing by Decca. In these circumstances skywave effects may well be present at times (*see* Volume 1, Chapter 3, Section **34**, and Section **19** of this chapter).

Taut wire provides one of the best methods of checking the behaviour of Decca under these conditions. If a taut wire run is made either with or against the apparent tidal stream, the taut wire position lines will agree with the Decca fixes if the stream is real; if skywave is the source of the trouble the comparisons will not agree over a period of time; the Decca fixes will oscillate about the taut wire position lines in an irregular manner. This method of detection will not work if the apparent tidal stream is running at right angles to the ship's course made good.

However, if sounding has to be carried out when skywaves may be present, and the surveyor is worried by this fact, a taut wire line run in almost any direction will be a help, since it will provide a series of position lines in which he may have complete confidence.

c. Fixing by taut wire in boats

It is sometimes convenient to combine boat's taut wire with subtense methods, when fixing by the method described in Section **14b** above. Although the transit may be sensitive, the subtended angle may be too small when the boat is some distance offshore. In this case taut wire may be used to control the outer ends of the lines, the change over to subtense methods being made when this becomes prudent.

17. Fixing with Distance Lines

When sounding on very large scales, it is sometimes convenient to use a distance line to provide one position line, the other being obtained from transits or theodolite angles as described in Sections **13** and **14** above.

Distance lines are normally used in one of two ways: with one end secured ashore and the other handled in the boat, or with the line itself suspended in catenary across a river or basin.

a. Distance lines between shore and boat

The distance line should be light, convenient to handle, and preferably made of a material that does not stretch or shrink too much when wet; if it floats so much the better. It must be marked in the conditions in which it will be used, and checked from time to time against a stable reference. If long lengths are to be used it may be necessary to provide flotation at intervals, to prevent the bight sagging below the surface. When a measurement is taken the line should be taut, but not too taut.

A Lucas sounding machine provides a ready made device for sounding by this method, but the wire can be awkward to handle both ashore and in the boat. The effect of the sag of the Lucas wire is discussed in Section **9d** of this chapter. In most cases it will be possible to neglect it; if necessary, small detachable floats must be fixed to the wire at intervals.

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* Decca Daylight is generally considered to last between the times when the sun's altitude is about 10°, although in the Persian Gulf skywave effect has been observed to commence when its altitude was over 20°.

If the measured distance is not horizontal it will always be too great, and the true distance will equal the measured distance multiplied by the cosine of the angle of slope. The slope correction may, or may not be plottable, depending on the scale of the survey; it is most likely to affect short measured distances.

b. Distance lines suspended in catenary

If circumstances permit, a marked line or wire may be stretched across a river or basin. The sounding boat may then proceed along, or immediately below the wire, fixing as the marks on the wire come abreast the sounding position. There is no need for transits, as the wire provides both the position lines for a fix.

On large scales the sag of the wire will have to be taken into account. The formula quoted in Volume 1, Chapter 3, Section **91** will provide a reasonable value for it. The following working rules may be helpful:

(1) Make the wire as light as possible and the tension as great as possible, being careful to mark the line under its working tension.

(2) If the unsupported length of the wire is doubled the sag will increase eight times. (Sag varies as the cube of the length.)

(3) If the weight of the wire is doubled the sag will increase four times. (Sag varies as the square of the weight.)

(4) If the tension is doubled the sag will be reduced four times. (Sag varies inversely as the square of the tension.)

In practice the presence of a plottable sag correction in a distance line set up in catenary for sounding will generally mean that the method is unsuitable.

18. Fixing by Radar

The measurement of distance by radar is discussed in Volume 1, Chapter 3, Section **28**. It may be seen there that, with a well adjusted and well calibrated set, it is possible to obtain individual radar ranges accurate to within a few yards. The accuracy obtainable over long periods in a sounding vessel will depend very much, of course, on the design of the radar set in use; using the most sophisticated modern equipment, and after applying corrections for the gonio, index, and speed errors referred to in Volume 1, Chapter 3, Section **28g**, it will generally be prudent to assume that errors in radar ranges obtained from a moving sounding vessel may be as much as 10 or 15 yards. The largest scale for which radar fixing will be suitable can be assessed from this assumption. If gonio corrections are not applied, errors in observed ranges may well be nearly double those quoted above. The speed error should always be found and allowed for, since it can be quite large; it is not very likely to change much from day to day. Experience at sea indicates that comparatively minor adjustments to the pulse forming circuits in a radar transmitter can change the index error quite appreciably.

When fixing by radar the performance of the set should be checked each day before starting work. Radar ranges may be compared with fixes obtained by sextant or some other equally precise method, to make certain that they are correct.

It is normal when sounding by radar either to obtain ranges to two well disposed objects, or to obtain one range and combine it with a suitable sextant angle. Both methods produce two position lines for each fix. The criteria for a good fix are the same as those which apply to visual work: the position lines must be sensitive, and they must cut at a good angle.

a. Radar marks, reflectors and transponders

(i) Natural marks. For a natural mark to be suitable for use as a radar target when sounding, the surveyor must be able to identify its echo on the scan without any doubt at all. Few marks are obliging enough to meet this requirement. Isolated rocks (the higher and more rugged they are, the better), lattice masts and light structures sometimes make good targets; a great deal depends on their surroundings. In many cases it will be necessary to use reflectors or transponders, which are described below.

(ii) Radar reflectors; the Luneberg lens. To be of any use to the hydrographic surveyor sounding by radar, a reflector must be accurately made, strong, reasonably light, and easy to erect and dismantle both ashore and afloat. It should have good reflecting qualities at the frequencies employed, but it is perhaps more important that it should reflect reasonably well over fairly wide angles in both the horizontal and vertical planes.

The corner reflector illustrated in Fig. 3–36(a) has been used successfully for many years in the Surveying Service of the Royal Navy. It consists of three square plates of light sheet metal (aluminium alloy is very suitable), fitted together in three mutually perpendicular planes. The response of this reflector is omnidirectional, and it is very suitable for fitting to floating marks. A reflector which has been used successfully ashore is shown in Fig. 3–36(b). It consists of three right angled isosceles triangles of sheet metal, fitted together along their short sides; its response is more directional than that of the corner reflector, and therefore it must be mounted with its open end approximately vertical and pointing towards the survey area.

The efficiency of both these reflectors falls away rapidly if the sides are not flat, or are not assembled at right angles to each other; care must therefore be taken when constructing them to ensure that these points are not overlooked, and they must be handled gently.

The greatest range at which reflectors can be detected by radar depends, amongst

RADAR REFLECTORS

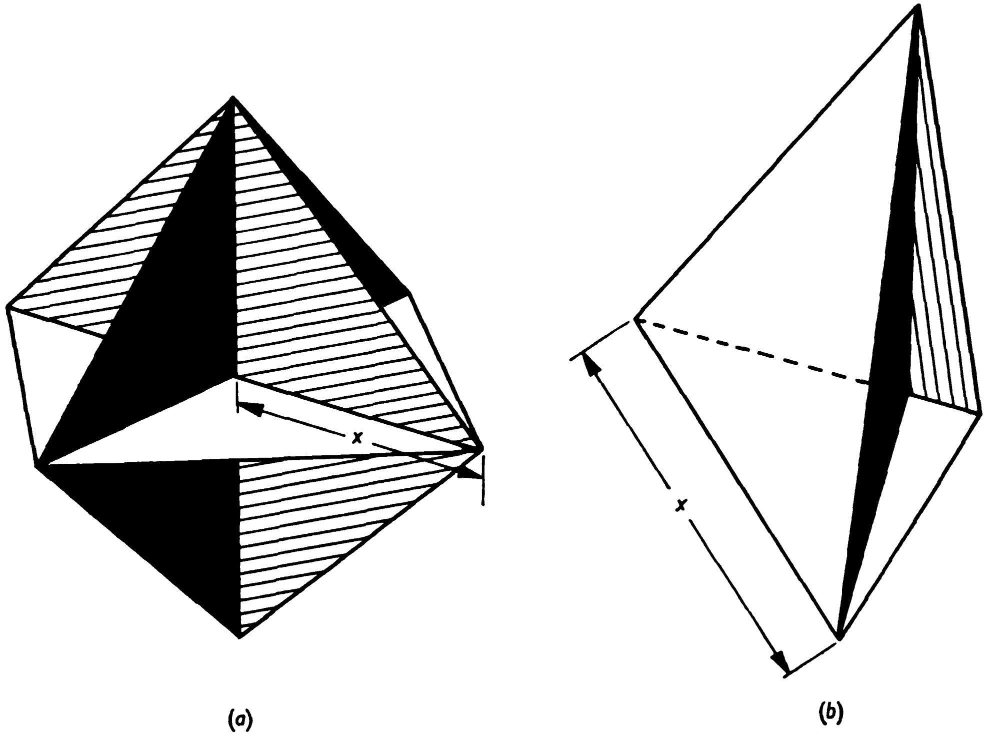

Fig. 3–36

other things, on the area of the reflecting surface. The table below shows approximate maximum working ranges for various sizes of reflector, tabulated against the length of the shorter sides of the right angled triangles (x in Fig. 3–36(a) and (b)). It is based mainly on theory, and may be modified as more knowledge is obtained; it assumes that the 'line of sight' between the reflector and radar aerial is not obstructed by the horizon or anything else, and that the wavelength of the radar set is about 3 cm.

MAXIMUM WORKING RANGE OF RADAR REFLECTORS

RANGE IN MILES (of 6,080 ft)	x IN INCHES
2	5
4	10½
6	16
8	21
10	26
12	32
14	37
16	42
18	47
20	53

In Fig. 3–37 the ship is ranging by radar on the reflector. Most of the radio energy will travel by the direct path; but some will be reflected off the surface of the sea, travelling by the reflected path. If the sea is calm this reflected component may be relatively quite large.

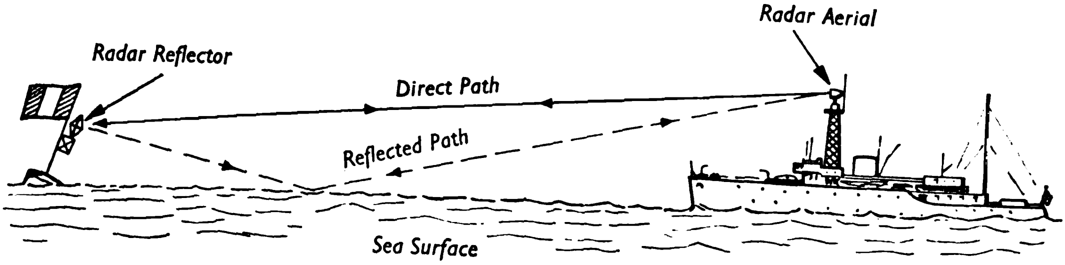

Fig. 3–37

The energy travelling via the reflected path will increase or decrease the strength of the echo on the radar screen, depending on whether it is in phase or out of phase with the direct path energy as it arrives back at the radar aerial. The strength of the echo will therefore fluctuate slowly as the ship moves towards or away from the reflector. If the reflected component is relatively large the echo may disappear at ranges well within the theoretical maximum,* to appear again quite strongly as the vessel opens or closes the target. This effect depends on:

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* Reflectors mounted on floating beacons have given no response at ranges of four miles, and yet given strong echoes at 10 miles.

(*a*) the frequency of the radar set;
(*b*) the height of the vessel's radar aerial;
(*c*) the height of the radar reflector;
(*d*) the range;
(*e*) the reflecting qualities of the surface over which the energy is travelling. A calm smooth sea produces the most pronounced effect.

The simplest way to overcome it is to fit two reflectors on the target, one being about half the height of the other. It is very unlikely that minimum amplitude echoes will be received from both reflectors at the same range.

The Luneberg lens has been developed for use as a radar reflector. It is more expensive than the reflectors described above, but is more efficient and has a greater angle of response in all three dimensions. It consists of a sphere of dielectric material fitted with a backing of reflecting material in the form of a cap or ring. The spherical lens focuses the incoming radar energy to a point on the reflecting surface, and then redirects it back along its original path. Individual lenses can only be used over a comparatively small range of radar frequencies.

(iii) Radar transponders. A radar transponder consists of a small receiver-transmitter which amplifies an incoming radar signal and then transmits it back to its source. To be useful to the hydrographic surveyor such a device must be portable, reasonably compact and light, and must have self contained power supplies; these are generally obtained from a battery.

The incoming radar energy may be retransmitted on a slightly different frequency, to which the receiving equipment in the ranging vessel is accurately tuned; this will cause the transponder's echo to show up very well on the trace, even if it is surrounded by echoes from natural objects, since the radar receiver will not amplify the natural echoes nearly so much as the artificial one to which it is accurately tuned.

Several practical difficulties must be overcome in the manufacture of a transponder. It is not easy to handle the very high frequencies involved, in a small portable unit. Neither is it easy to ensure that the transponder delay (the time taken for the signal to pass through the transponder) remains constant; battery power supplies tend to aggravate this problem. For the best results the transponder's aerial system should receive and transmit equally well over a wide angle in all three planes; this requirement is not easy to satisfy in practice.

The first production models of a portable transponder are being tested at sea (in 1965), and it seems probable that they will make radar fixing much more attractive to the hydrographic surveyor. They should be sited clear of, and preferably above and in front of, objects such as railings, which may re-radiate on radar frequencies.

Ranges obtained on a transponder will always be greater than they should be, owing to the transponder delay. The 'index error' of a transponder, which may be as much as 300 yards, should be found before it is used, and checked from time to time to make sure that it remains constant.

b. Obtaining radar range while sounding

(i) Ranging on a single object. The procedure is relatively simple. Care must be taken to set the gain and clipper controls correctly (if in doubt too much gain is better than too little), and to align the ranging crosswire properly on the leading edge of the echo. If the fix is not obtained at the instant at which the target paints on the radar screen, allowance should be made for the vessel's movement. The Dalrymple radar range corrector, described in (iv) overleaf, may be used.

The following table shows the distance travelled in three seconds (one rotation of the aerial at 20 r.p.m.) by a vessel moving at various speeds:

SPEED OVER THE GROUND	DISTANCE TRAVELLED IN THREE SECONDS
knots	*yards*
5	8⅓
10	16⅔
15	25
20	33⅓

(ii) Ranging on two objects; simultaneous observations. If two ranging panels are available, the procedure for ranging on two objects is very similar to that described in (i) above. Allowance may have to be made for the vessel's motion, since the two ranges can never be observed at the same instant, owing to the finite speed of rotation of the radar aerial. It will generally be better to obtain a fix as the target whose range is changing more rapidly (it will nearly always be the one whose relative bearing is furthest from the beam) paints on the scan.

(iii) **Ranging on two objects; mean range method.** Suppose that only one ranging panel is fitted, and that it is required to range on two objects, *A*, whose range is changing comparatively slowly, and *B*. The procedure is as follows:

(*a*) Obtain a range on *A* as it paints on the scan.

(*b*) Obtain a range on *B*; this instant will be the fix.

(*c*) Range on *A* once more.

The two values for the range on *A* are meaned to give a value which may be equated with the range on *B*. The time intervals between the observations must be equal, and reasonably short.

This method is most useful when a vessel is steaming along lines of constant range from *A*.

(iv) Ranging on two objects; corrected range method; the Dalrymple radar range corrector. If only one ranging panel is fitted, and it is required to range on two objects, a correction may be applied to the second range observed, to allow for the ship's motion during the time interval between observations. This correction can be found quickly on the Dalrymple radar range corrector, which may be made on board from sheet metal, plastic, or Bristol board. The corrector, which is illustrated in Fig. 3–38, consists of a central disc and an arm, both of which can be rotated concentrically and independently within a compass rose scribed on the baseplate. Several parallel lines, spaced at 10-yard intervals, are engraved on the disc at right angles to the ship's course made good, which may be set against the compass rose with the index mark. The arm is graduated in time intervals corresponding to a particular speed of advance over the ground, using the same distance scale as that on the disc. It must be changed whenever the speed of advance alters more than half a knot; in the figure the 10-knot arm is being used.

The procedure for obtaining a correction is as follows:

(*a*) Fit the arm corresponding to the vessel's speed made good over the ground.

(*b*) Set the central disc to the course made good, and the arm to the bearing of the second object being ranged on.

(*c*) Measure the time interval between the two range observations by stopwatch or other means.

THE DALRYMPLE RADAR RANGE CORRECTOR

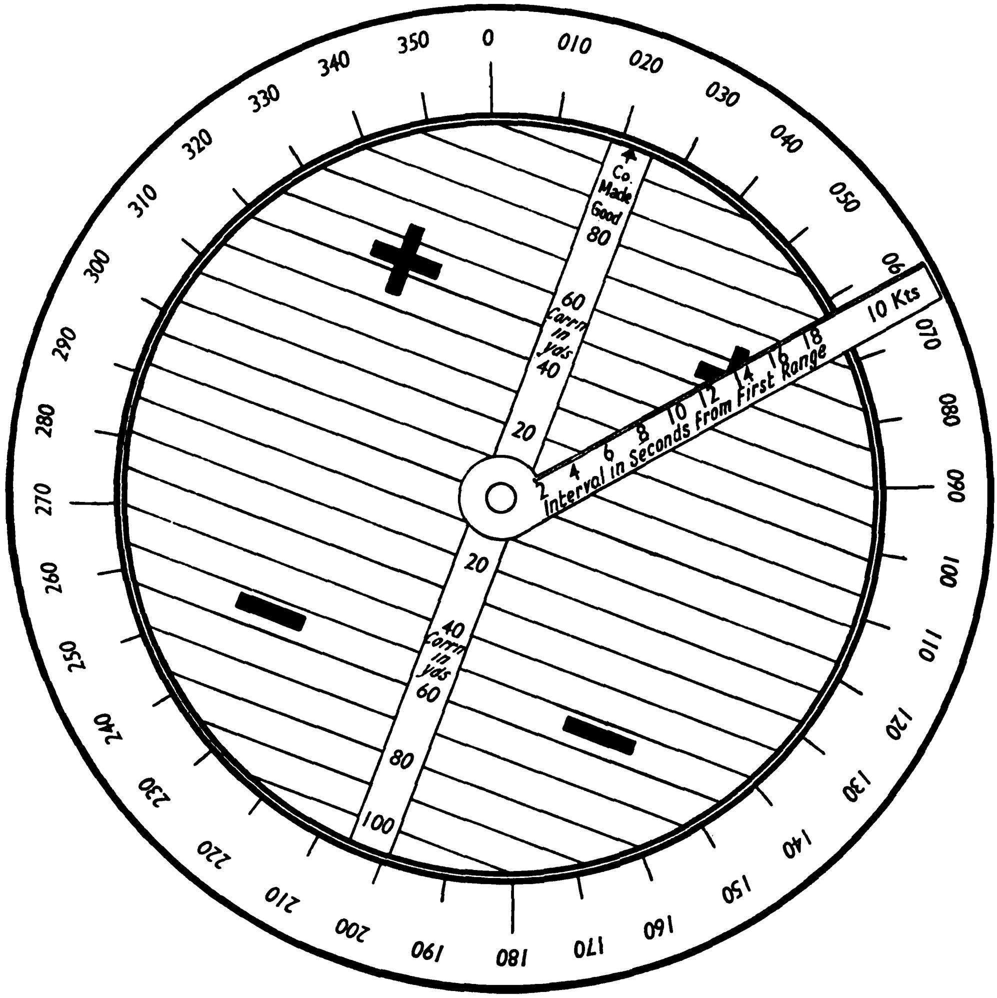

Fig. 3-38

Then the correction to the second range may be read off on the disc against the appropriate time interval on the arm. If the relative bearing of the second object is forward of the beam, its range must be increased by the correction; if it is aft of the beam, the correction is subtractive.

In the figure the course made good is 022°, and the bearing of the second object is 062°. For a time interval of 14 seconds the correction is 59 yards; this must be added to the second range to reduce it to the time of the first.

c. Plotting radar fixes

Sounding fixes in which radar has been used may consist of two radar ranges, or one radar range combined with a position line obtained by visual or other electronic methods. Some pure radar and radar-visual methods of plotting are described below; these may be developed by the surveyor in the field to meet his own requirements.

(i) Plotting by beam compasses. If only a few fixes are to be plotted beam compasses may be used with advantage. The method is not recommended for general work, however, since beam compasses are not easy to set and handle, particularly if the plotted distances are large.

(ii) Plotting by range curves. Curves of constant range may be drawn on the sounding board round the various radar marks, and the fixes interpolated between them by eye. It may be necessary to allow for a varying scale factor when drawing the curves, which will not in theory be true circles on the board. (*See* Volume 1, Chapter 6, Section **19a.**) This method is very convenient, especially on small scales, or if the marks are not on the sounding board; however, the production of the curves takes some time, and there may be the danger that too many families of curves will make the board confusing.

Both these drawbacks are avoided if the curves are drawn on an overlay of transparent stable plastic. This is placed on the sounding board, and adjusted until the ranges to the two marks being used coincide with their plotted positions; the vessel's position is then at the centre of the concentric 'circles'. If two overlays are prepared, one may be centred on each of the marks, and the fixes interpolated by eye in the same way as if the circles had been drawn on the board. The use of overlays is recommended for large scale work, and if a lot of radar marks are being used during the course of a days work.

(iii) Plotting with the Sevenoaks plotter. The Sevenoaks plotter, which is illustrated in Fig. 3–39, can be made on board, and used in a manner analogous to that employed with ordinary station pointers.

Two graduated arms of brass or aluminium alloy carry scales of radar range; these scales may either be engraved on the arms, or more conveniently drawn on paper or plastic which has been stuck to them. It may be necessary to take into account a varying scale factor. They are secured to two shorter arms, which pivot about the plotting hole, by the two knurled screws; radar index error, or transponder delay, may be allowed for by setting index marks on the short arms against the appropriate radar ranges on the scales, before clamping.

In use the appropriate range on each arm is set against the plotted positions of the radar marks; the ship's position is then marked through the central plotting hole. The angle of cut of the radar position lines is the angle between the arms as the fix is plotted.

Provided the marks are on the board this plotter provides the most convenient method of plotting two radar ranges to obtain a fix. It may also be used with Two Range Decca, Hi-Fix and Hydrodist.

(iv) Plotting with modified station pointers; radar-visual fixing. If graduated strips of paper are secured to the legs of an ordinary station pointer, it may be used to plot a fix consisting of two radar ranges.

It may also be used to plot a fix where one radar range and a visual angle have been observed. In this case special care must be taken to guard against 'circular fixes', since the rules governing them are very different from those which apply to pure resections. As always, the safest course is to visualise the position lines on the board, and to make sure that they cut at a good angle.

An excellent fix may be obtained in otherwise impossible circumstances by measuring a small visual angle between two well spaced marks, and obtaining a simultaneous radar range to either (but preferably the nearer) of them. The smaller the angle the nearer will the cut of the position lines be to 90°. For a firm fix the rules governing a transit must be satisfied, i.e. the distance between the marks should not be less than one third of the distance between the ship and the front mark.

Such a fix may be plotted with the modified station pointers described above. Or,

THE SEVENOAKS PLOTTER

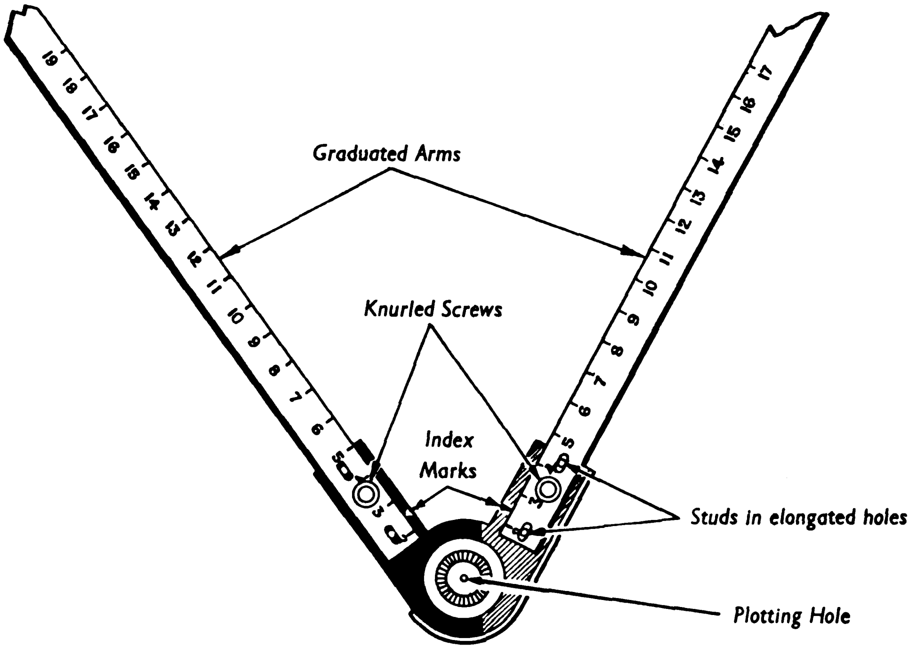

Fig. 3-39

provided the visual angle is not too great (10° or 15°), a protractor drawn on transparent stable plastic may be used. The index line of the protractor should be graduated in radar range. Angular graduations at about every 15′ of arc should be drawn around the periphery of the protractor, which is used in a way similar to the normal Cust.

19. Fixing by Two Range Decca or Lambda

The principles which govern the operation of Two Range Decca and Lambda are set out in Volume 1, Chapter 3. The *Admiralty Manual of Navigation*, Volumes 1 and 3, contains general information on Hyperbolic Decca, much of which (and particularly those parts treating the ship-borne receivers and decometers) is applicable to two range operation. The Decca Navigator Company issues handbooks with its equipment, which give detailed operating instructions.

In what follows it is assumed that the surveyor has assimilated all this relevant information, and has a thorough grasp of basic principles.

a. Preparation for fixing

Assuming that the equipment is operating correctly, the following points must be attended to before it is used for fixing:

(i) Instrumental checks

(*a*) Decometer corrections should be noted, if they are significant, so that they can be applied to the observed readings. (*See* Volume 1, Chapter 3, Section **30d.**)

(*b*) The locking constant should be applied to the goniometers, or noted, so that it can be applied to the observed readings. (*See* Volume 1, Chapter 3, Section **32c.**)

(*c*) The receivers, decometers, and track-plotter if one is fitted, should be referenced, taking care to allow for the locking constant if necessary. Since the phase measuring circuits are not completely stable, referencing should be carried out at least once an hour whilst sounding is in progress. If the ship is moving, great care must be taken not to slip a lane whilst this is being done; it is safest to reference when the pointers of the decometers are near the whole lane graduations.

(*d*) If the phase lag has not been allowed for in the preparation of the plotting sheet, it must be noted, so that it can be applied to the decometer readings.

(*e*) After referencing, the test push should be pressed. The correct deflection of the decometer pointers indicates that signals are being received from all stations and phase measurement is taking place. A decometer which does not deflect properly on 'test' should not be used until the trouble has been diagnosed and rectified.

(*f*) The decometers should be set to the correct lane, and lane numbers noted on the track plotter record if one is being used. Lambda provides its own lane identification, but this can be wrong if the 'notching' procedure at the slave stations is not carried out correctly. With ordinary two range equipment the correct lane can be established at a co-ordinated floating mark, or by obtaining a visual or radar fix.

(ii) Establishing the limits of decca daylight; skywaves. The effect of skywaves on Two Range Decca is discussed in Volume 1, Chapter 3, Section 34. Decca daylight is defined as that part of the day when the decometer readings may safely be assumed to be free from the effects of skywave, on the plotted scale of the survey, i.e. it will not be possible to plot skywave errors. This period may, in certain conditions, extend throughout the entire day and night, but the surveyor would be foolish to make this assumption without checking. The effect of skywave on a ship being conned along a line of soundings is to introduce a spurious, though very apparent, tidal stream. The surveyor will find that he is not holding the line, and will alter course to do so. If he is a capable ship sounder, the ship's plotted track will appear to be correct, the sounding lines being straight and regularly spaced; the recorded decca fixes will agree with the plotted track; but both will be in error by an amount (which may in extreme cases be well over half a line on the sounding board) caused by the unknown, unrecorded, and variable skywave effect. At the present time (1965) nothing can be done about skywaves. The only safe course is to sound only during decca daylight.

At the start of each survey the duration of decca daylight should be established in the following way. Two sets of observations are required: the p.m. set should commence well before the possible onset of skywaves, and the a.m. set at the time when it is desired to start sounding.

(*a*) Anchor the ship on a fairly short scope (two anchors are recommended) anywhere in the sounding area. If the ship can be moored alongside so much the better. If the survey area is large two or three sets of observations may be needed, in different positions. Land effects need not be considered, since the stability of the patterns, and not their absolute accuracy, is to be tested.

(*b*) Switch on the track plotter, using a scale of about four inches to one lane. Mark the stylus position with the time every 15 minutes or so. If a track plotter is not available read the decometers every 15 minutes and make a graphical plot.

(*c*) In the absence of skywave the ship's yawing movement round her anchors will produce a small crescent shaped mark on the plot. If and when skywave affects the decometers, the ship will apparently get underway, and may 'move' as much as half a lane or so in 10 or 15 minutes. The onset of skywave effect in the evening and its disappearance in the morning can thus be determined. Sounding should not be carried out between these times unless the errors are not plottable.

Fig. 3–40 shows a typical track plotter record. It can be seen that skywaves come in at about 1715, and that the amplitude of their swing is equal to 0.65 red lanes, or about 280 metres; this is equivalent to about 0·15 inches on the sounding board, on a scale of 1/75,000.

(iii) Calibrating in the survey area; the effect of drying banks. If possible a Two-Range Decca chain should be calibrated in the survey area from time to time, to make certain that the locking constants are in fact constant. Experience has shown that the presence of drying banks, or a large expanse of tidal foreshore in a transmission path can cause the locking constant to vary with time. The effect usually is that the decometers start to read too much as the banks uncover, and the mean conductivity of the transmission path falls; it can sometimes be very plottable. The best way to detect it is to obtain a series of comparison fixes between decca and

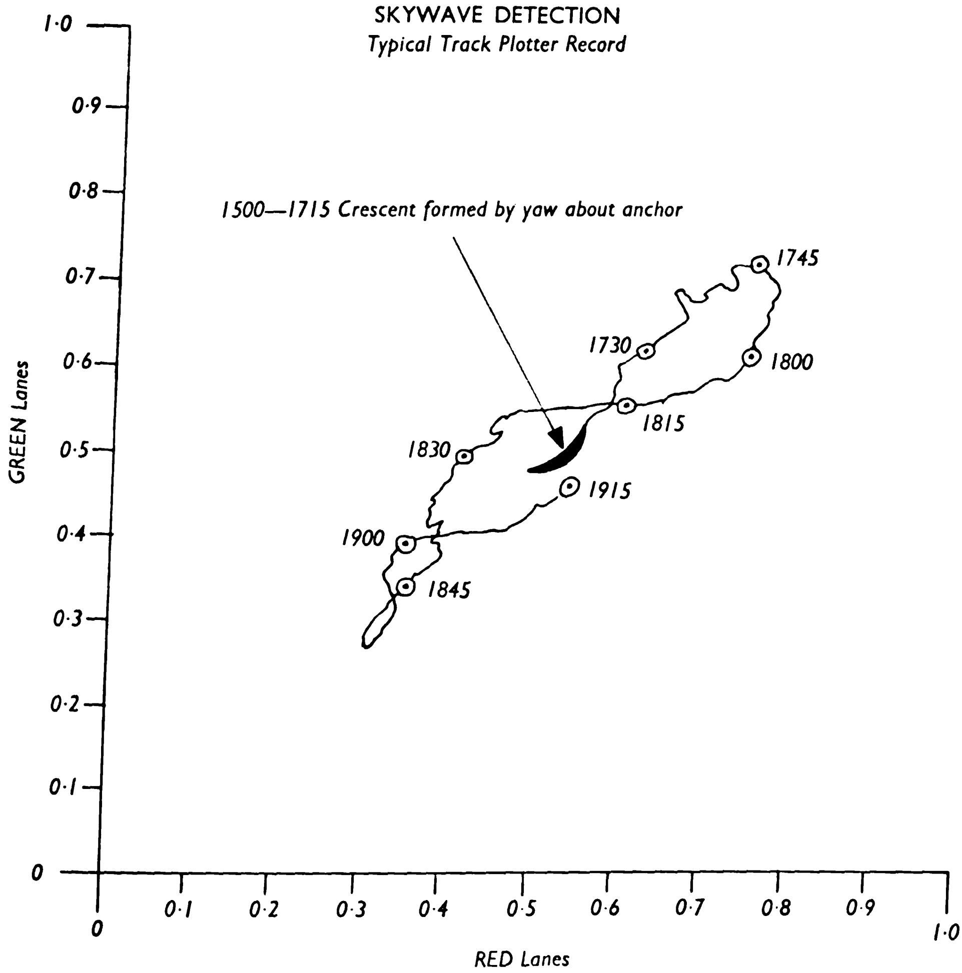

Fig. 3–40

some other reliable fixing method over at least one, and preferably two, tidal cycles, at spring and neap tides if the variation in range is great.

To date (1965) the effect of drying banks has been noted and allowed for in isolated cases;* but no controlled observations have been obtained with a view to discovering whether there is any definite relationship between the rise and fall of the tide and errors in the decometer readings. Such observations would be most valuable in advancing the surveyor's knowledge and understanding of the behaviour of decca and other radio transmissions.

(iv) Choosing the direction of the lines of soundings when fixing by Two Range Decca. It is very tempting, when sounding by Two Range Decca, to run the lines parallel with one set of decca curves, making small alterations of course from time to time so as to keep one of the decometer pointers stationary. In theory small deviations from the intended track should immediately be apparent, and it it should be very simple to hold the line.

However, in practice even a decometer pointer's bearings produce more friction when they are stationary than when they are moving. A stationary pointer will generally give the first indication that the ship is off the desired track by jumping two or three hundredths of a lane. The result is that in practice the surveyor does not have quite the delicacy of control that theory would indicate.

An alternative, and perhaps better, method is to run the lines of soundings at an angle to both patterns, in the direction which best delineates the underwater contours. Both decometers will then be moving the whole time, and their greater sensitivity will probably more than offset the advantages to be gained by running the lines along one of the patterns.

b. Two Range Decca; fixing and plotting

When sounding by Two Range Decca it is best to obtain a fix every time the more rapidly moving decometer pointer indicates a predetermined fraction of a lane; fixes obtained on the whole or half lane are most convenient, as these values are particularly easy to plot. The on-line reading of the other pointer may be taken off the sounding board before a fix is obtained, and compared with the observed reading at the fix, enabling the surveyor to know as soon as the fix is taken (and before it is plotted) whether or not he is on the line. The time should be noted at each fix in the usual way; time intervals between fixes will probably not be constant, owing to tidal stream effects, but this does not matter, since the fixes themselves are evenly spaced on the board. It is a good idea to tap a slowly moving decometer very gently just before each fix to overcome the slight friction in the bearings; for this same reason the decometers are usually more sensitive if their faces are horizontal rather than vertical.

Plotting may be carried out with the aid of a finely graduated ruler, or a plastic ruler especially constructed for a particular survey, and graduated in fractions of red lanes along one edge, and green lanes along the other. The plotting disc illustrated in Fig. 3-41 is recommended for all major Two Range Decca surveys, where the slave stations cannot be plotted on the sounding board. It may be made on board from stable plastic, and enables any fix to be plotted very quickly, in one operation. If the positions of the slave stations are on the board, the use of the Sevenoaks plotter is recommended (*see* Section **18c(iii)** above), since it will not then be necessary to draw the two range curves.

c. The track plotter

The track plotter is driven from the decca receiver through a power amplifier. One of

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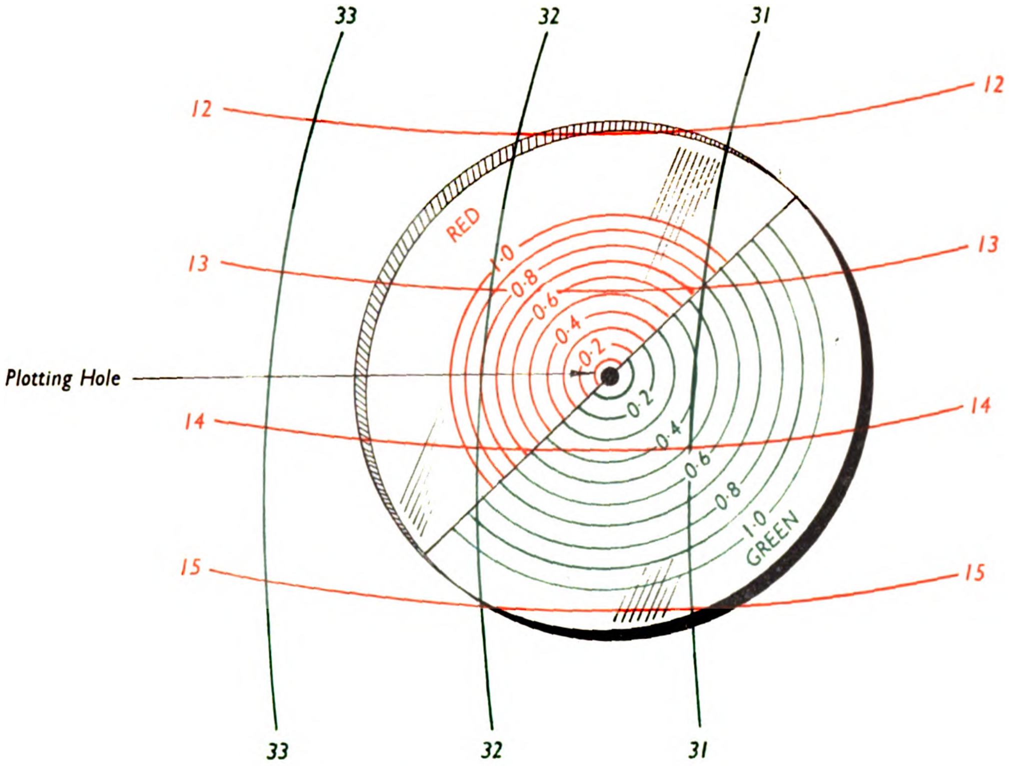
* The drying banks in the Wash and the Thames Estuary have been observed to cause this effect. In the Wash a large expanse of tidal foreshore and semi-tidal saltmarsh also lay in the transmission path.

TWO-RANGE DECCA PLOTTING DISC



The Setting of the disc is Red 13·52
Green 31·39

Fig. 3–41

the pattern outputs drives a pen across a strip of squared paper mounted on rollers, which themselves are driven by the output from the other pattern, causing the strip of paper to move up or down across a platen. These two drives can be interchanged.

The speed of each drive on the plotter can be varied in steps, thus altering the scale and shape of the plot; it is also possible to reverse the direction of motion of both the pen and the paper at will.

Since the motion of the track plotter is rectilinear, whilst the decca patterns it is plotting are made up of curved lines cutting at varying angles, there is bound to be distortion in the track plotter record. The purpose of the various switches and gear ratios is to enable the surveyor to reduce this distortion as much as possible. In practice it causes no inconvenience during sounding operations.

The track plotter provides a continuous and up to date record of the ship's track, and saves a great deal of time when turning on to a new line of soundings, recovering a lost line, or interlining, particularly in a tideway. Its use is strongly recommended. The largest scale compatible with reasonably economical use of the recording paper should be used.

A track plotter should be referenced in the same way as the decometers. Care is necessary when doing this, as its 'Ref.' button causes the decometers as well as the track plotter itself to reference when it is pushed, and sometimes makes them slip a lane unnoticed.

d. Lane slipping—detection and avoidance

Lane slipping may be classified into two types.

That caused by skywave effect is insidious and relatively gradual in its mode of operation. During a period when skywaves are strong, one or more lanes may be slipped. The decometers may rotate at the wrong speed, either too fast or too slowly, or they may refuse to rotate altogether, owing to a complete lack of torque. It is quite possible for the lane slipping process to be reversed within a relatively short period, and for slipped lanes to slip back again of their own accord, so that the surveyor never becomes aware that anything was wrong. Lane identification is no help, as it too will be influenced by the skywave effect.

At the present time (1965) nothing can be done about this type of lane slipping; it is generally detected more effectively by intuition than by reasoning, but experience indicates that both methods can be most unreliable on occasions. The only way to avoid it is to stop using decca when skywaves are strong. (*See* **a(ii)** of this section.)

The second type of lane slipping is that caused during good operating conditions by malfunctioning or maltreatment of the decca equipment. Careless referencing of the decometers or track plotter can cause the pointers to register one lane in error. Local transmissions on radio frequencies close to those used by decca cause the decometer pointers either to deflect or 'freeze', and if their readings are changing fast, a lane may be slipped. Thunderstorms and tropical disturbances can produce the same effect. Intermittent faults, both in the decca transmitters and receivers, can cause lanes to be slipped. All these effects can be avoided by vigilance and careful maintenance and operation of the equipment.

If lane identification is fitted a slipped lane should be obvious at a glance. If it is not available careful plotting, and a continuous monitoring of the ship's course and speed, is the best method of detection; the track plotter can be most useful. If it is suspected that a lane has been slipped it is not desirable to alter the vessel's course or speed until the doubt has been resolved.

When anchoring for the night, if no visual or other method of checking decca is available, the decometers should be read as the anchor is let go; they may then be reset to the same value the next morning as the cable comes up and down. If a small floating mark is laid on anchoring it will provide a good check against dragging.

20. Fixing by Hyperbolic Decca

The principles which govern the operation of hyperbolic decca are set out in Volume 1, Chapter 3. The *Admiralty Manual of Navigation*, Volumes 1 and 3, and the maker's handbooks, contain valuable general information on the system. Section 19 above is also generally relevant to hyperbolic decca.

In what follows it is assumed that the surveyor has assimilated all this information, and has a through grasp of basic principles.

a. Preparation for fixing

All the points set out in Section 19a above apply.

There is no locking constant in a hyperbolic system, since it is removed when the patttern is set. However, there will be 'fixed errors', which must be determined and allowed for. Experience has shown that these so-called fixed errors are anything but fixed from the surveyor's point of view. They can vary quite quickly with change in the ship's position (half a lane in 10 miles has been observed), particularly where small changes in position can create large differences in the nature of the various transmission paths, i.e. where one or more of the transmissions grazes a coastline, or suddenly starts to cross an island or promontory. They can also vary with time in the same place, if the conductivity of the land or 'sea' over a fixed transmission path alters appreciably; this effect can be caused by a change in the weather (heavy rain following a dry spell) or drying banks. For these reasons calibration in the survey area is very necessary when using a hyperbolic system; this calibration should be repeated from time to time sufficiently throughly to ensure that the fixed errors have in fact remained fixed.

Phase lag is not very likely to be plottable with a hyperbolic system. (*See* Volume 1, Chapter 3, Section **38f.**)

On the other hand a hyperbolic system is more likely to be affected by skywaves than a two range system, owing to the longer transmission paths.

b. Hyperbolic decca; fixing and plotting: the track plotter

The methods of obtaining a hyperbolic fix are similar to those employed in two range work. However, since the hyperbolic lanes are not parallel, neither the plotting disc nor the Sevenoaks plotter can be used for plotting; a graduated ruler of some sort must be employed. In theory a hyperbolic lane will only be reasonably accurately subdivided with a linear scale if the latter is laid along a curve of constant lane expansion factor; these curves are illustrated in Volume 1, Fig. 3–53, and may be sketched in or visualised on the plotting board. In practice, and provided the lane expansion and curvature are not too great, subdivision of the lanes may be made by using a ruler as a diagonal scale in the normal way. (*See* Volume 1, Chapter 6, Section **21d.**)

A track plotter may be used with a hyperbolic system in exactly the same way as with two range systems (*see* Section **19c** above). Its use is strongly recommended.

21. Fixing by Hi-Fix

Hi-Fix has been developed by the Decca Navigator Company to fill a need for a lightweight and easily transportable electronic fixing aid. Its principles of operation are similar to those of two range and hyperbolic Decca, although the way in which the phase comparisons are made is quite different.

A Hi-Fix chain consists of a master station, which may be shipborne (two range), or ashore (hyperbolic), and two slave stations. Each station transmits in turn on a common frequency of about 1,900 kc/s (wavelength 158 metres), the sequence being controlled from the master station. Memory circuits in the various receivers 'memorise' the phase of the signals which are not actually being transmitted at one particular instant, and so enable phase comparisons to be made.

Hi-Fix differs from Decca in the following ways:

(1) Transmitted and comparison frequencies in Hi-Fix are identical.

(2) The master and both slave stations use the same frequency. The lane widths of both patterns are therefore the same; along the baselines they are about 79 metres, depending on the exact frequency employed.

(3) The equipment is compact and portable, and the masts are relatively easy to set up, since none of them is higher than 30 feet.

(4) The narrow width of the Hi-Fix lanes, whilst making for greater potential accuracy, makes it more difficult for the surveyor to establish correct lane values when working with the equipment. A form of lane identification, working on the vernier principle, has been developed (in 1965) but as yet it is not entirely reliable.*

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* For various reasons it can only detect lane slipping with certainty. Nevertheless, it has proved to be very useful in practice.

(5) Hi-Fix does not (in 1965) seem to be affected by skywaves at ranges up to 50 miles or so, but this may well be because at these ranges there is very little skywave anyway.

(6) On the other hand it may well be more seriously affected than Decca by land path errors of all sorts; at present (1965) there is not enough evidence to enable a reasoned opinion to be given on this point.

(7) Although in theory Hi-Fix should be less affected by phase lag than Decca, in practice it seems that it is not. For the H.F. pattern, a phase lag factor of about 0·999535 (equivalent velocity 299,636 km/s) seems to be reasonable; for the L.F. pattern its value is 0·999635 (equivalent velocity 299,666 km/s).

In all other respects both the theory and practice of Decca apply equally well to Hi-Fix, and the reader is referred to Sections 19 and 20 above, and to the relevant parts of Volume 1.

22. Fixing by Hydrodist

Hydrodist is described in Volume 1, Chapter 3, Section 40. It is a development of the tellurometer, which is described in Section 39 of the same chapter.

A hydrodist fix consists of two time measurements, which are automatically converted into spheroidal distance by the application of a mean conversion factor (*see* Volume 1, Chapter 3, Sections **39n** and **39o**). These distances may be plotted in any of the ways described for use with Two Range Decca.

The following points should be borne in mind when using hydrodist:

(1) The equipment will only operate provided the direct radio line of sight is clear, i.e. to just beyond the optical horizon.

(2) The mean conversions factor built into the instruments is not very likely to be in error by more than one part in ten thousand. However, it may be if the meteorological conditions are very abnormal. Ground swing is neglected, and this is an additional source of potential (but relatively small) errors.

(3) Hydrodist observations produce spheroidal distances, and these must not be plotted directly unless it is safe to apply the 'flat earth policy'. It will generally be wise to apply the projection scale factor and grid scale constant.

(4) Some restrictions must be placed on the handling of a vessel using hydrodist, since it is not possible at present (1965) to rotate the master aerials continuously in one direction.

(5) Heavy rolling or pitching creates problems at the master units, both of holding the remote transmissions, and reading the correct values from the display. These are not, however, likely to become inconvenient except in large-scale work.

Part 3 Practical Sounding in Coastal Waters

23. Planning and Running Lines of Sounding

Before commencing to sound, the officer in charge of a survey must decide on a plan of operation. This plan must satisfy two basic requirements:

(1) It must provide for the delineation of the topography of the sea bed in the most economical and expedient manner.

(2) It must ensure that there is very little possibility that dangers to navigation will have been overlooked, when it has been completed.

A good sounding plan will be precise, yet flexible. The officer in charge will always know exactly what he intends to do one or two days ahead, and yet will never allow his plan to become so rigid that it cannot be altered overnight to deal with some unforeseen circumstance or discovery.

Experience is necessary when making a plan to sound out an uncharted area. Where a chart already exists the problem generally is easier. In both cases the principles outlined below may be applied.

a. The basic plan

The planned lines of soundings must cover the sea bed in a methodical manner. They should therefore be straight* and evenly spaced. The straightness of the lines actually run will depend on the surveyor's ability, and that of his assistants. He must know what to do if his actual lines of soundings are not straight enough, and when it must become necessary to reject a line altogether. He must also know what maximum spacing is permitted, before an additional line becomes necessary to fill in a gap.

In the Surveying Service of the Royal Navy it has been customary for many years to plan lines of soundings 0·2 inches apart, on the scale of the survey. The thoroughness with which the sea bed is inspected thus becomes a function of the scale of the survey; the greater the scale the more thorough will be the work.

Lines of sounding should generally be planned so that they run at right angles to the fathom lines. Where channels and banks exist, this method will usually delineate the bottom features in the shortest time. However, it would be unwise to be too rigid in this respect; there are times when it will be best to run the lines parallel to, or at an angle with, the trend of the fathom lines.

Where a chart already exists, the fathom lines will be shown, and planning will be relatively easy. In uncharted waters experience and even intuition must be used at times; it will generally be found, however, that the fathom lines follow the general trend of the coast.

Fig. 3–42 shows the planned lines of sounding, which it is hoped will properly delineate the underwater topography at the head of a gulf. The work has been shared between the ship and boats, and the ship lines have purposely been planned to run parallel with the trend of the fathom lines. In this area the bottom is relatively flat, and the advantages of being able to run long lines of soundings outweigh those of running the lines at right angles to the fathom lines. Where it is necessary accurately to fix a fathom

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* In some circumstances, e.g., when fixing by decca or using a fixed-angle plot, these 'straight' lines may actually be parts of regular curves.

PLANNING LINES OF SOUNDING

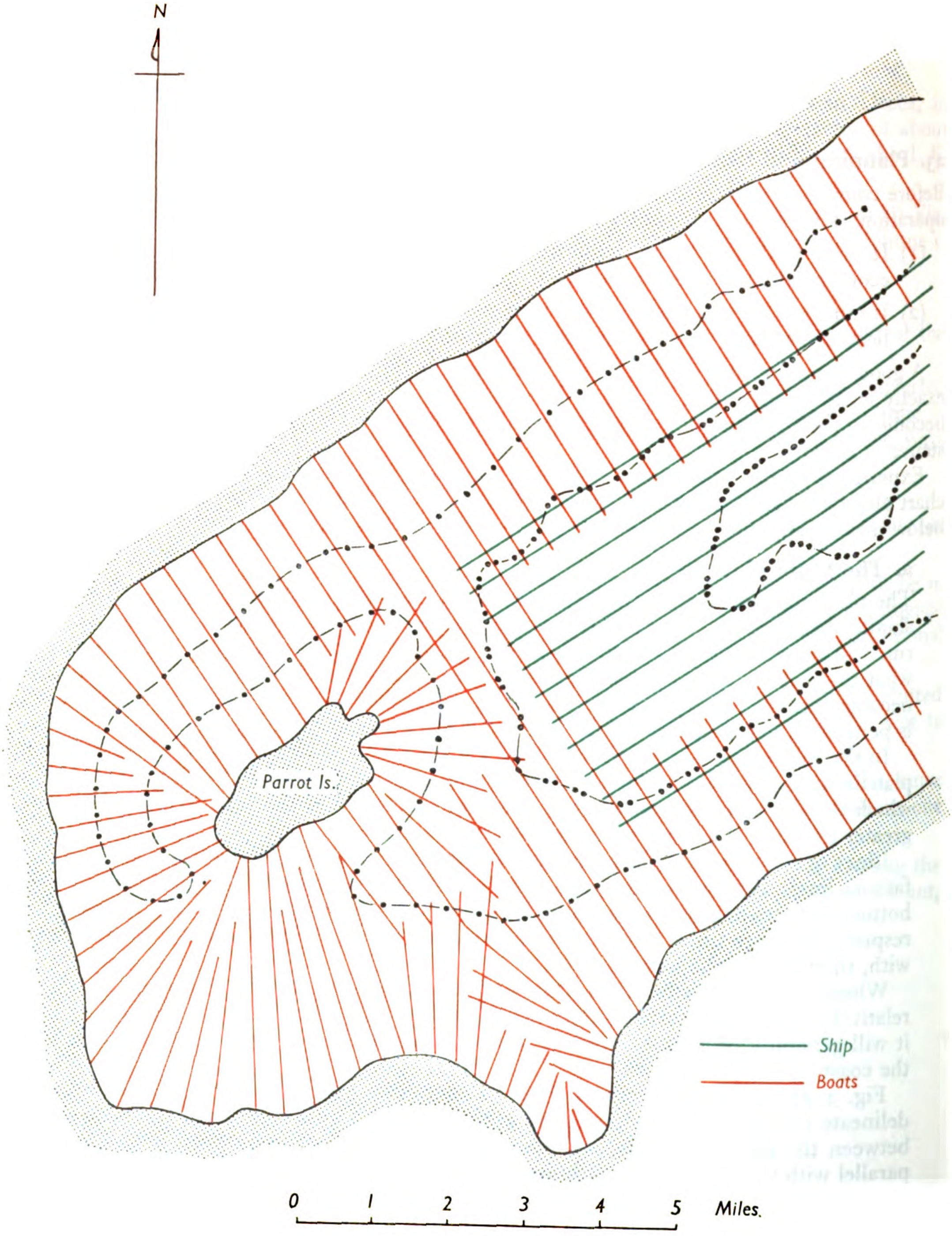


Fig. 3-42

line which is running between two lines of soundings, a few cross lines may be run, in addition to those shown in green.

Note how the boat lines have been starred round Parrot Island, and into the bay at the southern end of the area. Note too how no lines are anywhere more than 0·2 inches apart, and that there is a planned overlap between the shipwork and boatwork. This latter feature provides a check on the work of all units, and should always be provided for.

It must be stressed that the lines shown in the figure provide a guide as to how the sounding should be carried out. So long as the lines actually run are reasonably straight, spaced so that there are no gaps larger than those shown, and follow the general idea of the plan, there will be no point in trying to sound exactly along the red and green lines. Indeed, the surveyor who rejects an otherwise satisfactory line simply because it does not coincide with the planned line will be wasting time.

b. The importance of running straight lines of soundings

It is most important that the lines of soundings actually run should be reasonably straight. The only permissible exception to this rule is when the sounding lines are regular curves running along lines of constant subtended angle, constant radar range or constant decca, hi-fix, or hydrodist reading.

There are two reasons for this:

(1) Unless the lines are straight it will not be possible to space them evenly, and gaps will be left in the work, which will have to be filled in later with interlines or cross lines.

(2) More important perhaps, the surveyor who runs crooked lines will not be able to say with certainty just what path his vessel has followed between fixes; it is not very likely that this path will be truly represented by a straight line, or even a smooth curve, joining the fixes.

Fig. 3–43 shows two attempts at sounding out the same area; in both cases the pecked lines indicate the planned lines of sounding, spaced for clarity at double the normal distance apart.

In (a) the surveyor has concentrated on keeping his lines as straight and evenly spaced as possible, and has used the planned lines as a guide, rather than trying slavishly to follow them. His lines are not in fact completely straight, but it will be reasonable to assume that his vessel has moved along the firm lines joining the fixes. Note how after fix 15 he has made no attempt to regain either of the planned lines; he has satisfied himself with running a straight line parallel to those already run, and has then filled in the gap by running fixes 22 to 28. His work has covered the ground economically and methodically, and is good.

In (b) the surveyor has made the error of trying too hard to keep exactly on the planned lines. The result has been frequent and comparatively violent alterations of course, and a loss of that delicate control which is so necessary. His attempt to regain the 'next' line after fix 15 should not, in particular, have been made. The plotted track probably bears little resemblance to the true facts, particularly between fixes 3 and 6, 9 and 14, and 15 and 18. At the very least there are three awkward gaps in his work, marked *X*, which will have to be filled in later. There may very well be others, which are not apparent, since the plotted track between fixes cannot possibly faithfully represent the vessel's actual movements. This type of work should never be accepted, except from surveyors under training; if it is accepted, then it must always be checked with interlines and cross lines run by an experienced man.

c. Interlines

An interline is an additional line of soundings inserted between two previously run lines, generally so that it bisects the space between them.

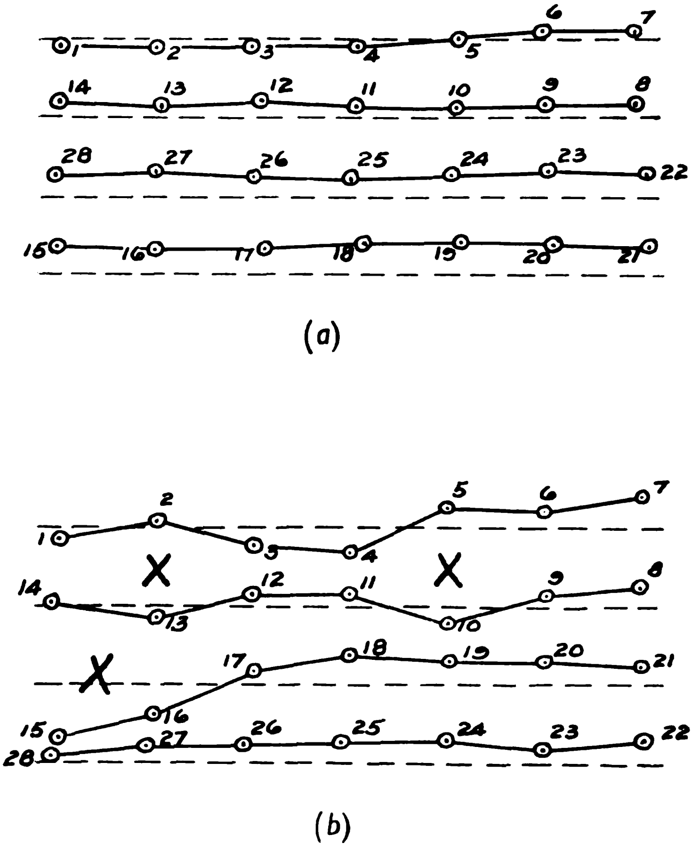


Fig. 3-43

Interlines are run for three main reasons:

(1) To fill in a gap in the work caused by bad management of the sounding vessel.
(2) To improve the thoroughness with which a particular area is sounded out.
(3) To investigate an indication of possible shoal water.

(i) Interlining to fill in gaps in the work. The aim of every sounding team should be to run straight and evenly spaced lines of sounding, generally 0·2 inches apart. At times even an experienced surveyor will not be able to do this. His coxswain may be inexperienced; the tidal streams may change unexpectedly and suddenly; fixing may be difficult, and so on. The result will be that his work does not satisfy the requirements of the sounding plan.

Provided, and only provided, the lines actually run are reasonably straight, gaps may be filled in with interlines. These should be run so that at no point are the actual lines of sounding more than 1½ times as far apart as the planned lines, i.e. the spacing should nowhere exceed 0·3 inches. If there is any doubt it will always be better to run two interlines to fill in a gap properly, rather than run the risk of missing a possible danger to navigation. These additional lines should always be run as soon as their need becomes apparent, so that the routine examination of a particular area is completed before the sounding vessel moves on to new work.

It is not easy sometimes to decide whether a particular line of soundings that has gone astray is straight enough to be acceptable. Judgement and experience are both necessary. The safest test to apply is as follows:

The surveyor must be quite certain that his plotted track, and particularly those parts of it between the fixes, faithfully represents the vessels actual track over the sea bed.

For example, in Fig. 3–43(b) it would be wise to reject all the work up to fix 18, since the alterations of course are so frequent and violent.

(ii) Interlining to improve the thoroughness of the work. The scale on which a survey is carried out usually takes into account the fact that normal lines of sounding will be spaced 0·2 inches apart on the sounding board; it is chosen so that there will be very little chance of a shoal being able to lie undetected between these lines. Other things being equal, the rougher the topography of the sea bed, the greater usually will be the scale of the survey.

However, it may be that when the scale of an original survey is decided upon the roughness of the bottom topography is underestimated. In such cases the throughness of the routine sounding may be doubled by running interlines, the decision to do so being taken by the senior surveyor on the spot.

Interlining is also advisable in important shipping channels and similar places where the depth of water is only just sufficient for safe navigation, and small irregularities on the sea bed might be dangerous.

The prudent surveyor will always run an interline if he has the slightest doubt concerning the suitability of lines spaced at the normal interval. The temptation to cover large areas quickly (and perhaps inadequately) must always be resisted.

(iii) Interlining when shoal water is indicated. Except in rock and coral infested waters it is very unlikely that a shoal dangerous to navigation will be able to lie upon a base small enough completely to escape detection on one or other of two adjacent lines of sounding, provided the scale of the survey has been properly chosen. The nearest line to a shoal should always give an indication of its presence. There will be a discontinuity in the slope of the sea bed, usually in the form of a hump on the echo trace, but sometimes taking the form of an unexpected deep sounding. Experience and judgement are required when dealing with these indications. If they occur roughly abreast each other on two adjacent lines of sounding a short interline should always be run to find out what lies between them. The golden rule is always to run an interline if there is any doubt at all.

In rock and coral infested waters it is even more important to run interlines to cover the slightest indication of shoal water. A rise of even a foot or two on adjacent lines of sounding half a cable apart may be all that shows to indicate the presence of an isolated rock or coral knob. Indeed, in some parts of the world pinnacle rocks and coral knobs can rise to the surface out of 20 fathoms on a base little over 100 feet across.

Interlining very often constitutes the first step in the detection and close examination of a shoal. If the interline is not run in the first instance, the shoal may well remain undiscovered.

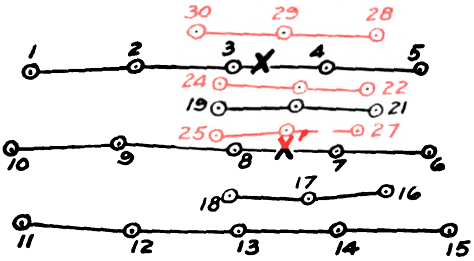


Fig. 3–44

Suppose that in Fig. 3–44 the surveyor has just run the three lines of sounding from fixes 1 to 15. Just after fix 3, at the point *X*, and half-way between fixes 7 and 8, at the point *X′*, he noticed humps on the echo sounder trace rising about three feet from an otherwise evenly sloping bottom, in general depths of about eight fathoms. He runs the interline, green fixes 16 to 18, and finds nothing unusual. He then runs green fixes 19 to 21, and just before fix 20 passes over a shoal which rises two fathoms from the bottom. To delineate it more completely he runs red fixes 22 to 24 and 25 to 27, and to make certain that it does not extend the other side of the original line he runs red fixes 28 to 30. He now has three interlines between his original lines of sounding, in the area of the shoal, and a good idea of its extent and the least water over it. This is about the limit to which it is advisable to go when a shoal is first discovered; if, when the work has been inked in and studied, a more detailed investigation is considered to be necessary, it will be best to carry out the additional work on a fresh board, and perhaps to conduct it on a larger scale. (*See* Section 24 of this chapter.)

d. Cross lines

Cross lines are lines of sounding run at an angle (generally about 90°) to the normal lines in a sounding plan. They are usually run for one of the following reasons:

(1) To ensure that narrow tongues of shoal ground do not extend at right angles to the shore off a point or headland. In Fig. 3–42 a few cross lines of this type might well be run off the north-eastern point of Parrot Island, where the starred lines might possibly miss a narrow tongue of shoal water extending from the shore.

(2) To delineate a fathom line accurately, where for some reason the normal lines fail to do this. In Fig. 3–42 the 30-fathom line may well not be precisely delineated by the ship's lines of sounding, which for the most part are running parallel to it. A few cross lines, which in this case might well cut the normal lines at an angle of about 45° (the ship zigzagging across the main channel to run them), will enable this fathom line to be drawn accurately.

(3) To check work which has already been carried out. Time spent in running cross lines right across an area which has been surveyed will never be wasted. If they agree with the original soundings the surveyor will have added confidence in his work. If they do not agree (they may not at times, particularly if the tidal observations have not been properly taken and applied), there will still be time to diagnose and rectify the trouble.

(4) To delineate a shoal more fully than can be done by interlining normal lines of sounding.

e. Delineating danger lines before starting to sound

It has been seen that normal lines of soundings are generally run at right angles to the trend of the fathom lines. Whilst this is perfectly proper, it can lead the unwary surveyor into trouble at times. A ship or boat steaming across the fathom lines in uncharted waters, and taking no special precautions, will sooner or later find herself heading straight for shoal water; if luck is not on her side she may even run aground.

In order to avoid this potential situation a danger line, beyond which the vessel must proceed with great caution, may be delineated on the sounding board before the main lines are run. If a chart of the area already exists, the danger line may be taken from it via the transfer tracing; but it should be remembered that the reason for the new survey being ordered may well be that the current chart is inadequate. In uncharted waters the sounding vessel should steam cautiously along the danger line, taking care to keep the ship's head roughly parallel with the fathom lines, and sounding as she goes. This line of soundings will not be wasted, since it will form a valuable check when the main lines have been run.

When a boat is sounding off an exposed coast in a swell the surveyor should always have a careful look at the line of breakers before starting work near it. From seaward, breakers always look more innocent than they really are, and the danger line in this case may well not be governed by the depth of water but by the breakers themselves.

f. Open lines of sounding

It is not always necessary to run lines of soundings at the normal spacing of 0·2 inches apart. For instance, no ship is likely purposely to set her course over drying banks flanking a navigable channel, or across a large expanse of drying foreshore. The surveyor may therefore confine his efforts to defining the drying line round these banks accurately, and obtaining sufficient soundings over them to show their maximum height above chart datum and their general configuration. This can usually be done by running lines across the banks at double the normal spacing, or by zigzagging backwards and forwards across them. Common sense must be used when deciding how best to deal with any particular problem, and it may well be prudent to sound in the normal fashion where heavy boat traffic is expected, or if a high water approach route for small vessels is involved.

In most coastal surveys there will generally be a fathom line, perhaps at 20 or 100 fathoms, outside which the spacing of sounding lines required for the inshore work will be too rigorous. Open lines of sounding may then be run in the deep water. It will usually be best to extend the normally spaced lines until it becomes safe to run every other line. Very often the surveyor's instructions will contain specific orders on this point. If there is any doubt it will always be safer to extend the normally spaced lines a little further to seaward than is really necessary, rather than run the risk of missing a shoal indication.

g. Test lines

In some areas, such as the approaches to the Thames Estuary, the navigational channels are so important, and change their configuration so rapidly, that regular resurveys are required. In others the desirability of carrying out a proper resurvey can best be deter-determined by running test lines from time to time.

These lines will usually be very open, and their positions must be carefully selected so that they will give a good picture of the general configuration of the bottom.

The surveyor ordered to run test lines will generally be given a very free hand. If no changes have taken place since the last survey his task will be simple and straightforward. Where changes have occurred the test lines must show their nature and extent with the minimum expenditure of effort. An instruction to run test lines in an area may well develop into a full scale resurvey, and the lines should therefore be planned with this possibility in mind.

h. Leading and clearing lines

Leading and clearing lines are most useful aids to navigation, and the surveyor should be constantly on the lookout to recognise any that may be of value. Before they are charted or recommended for use, such lines should be carefully sounded over; where the survey is incomplete or the sea bed is very irregular it may well be prudent to sweep along them in addition to sounding.

It is essential that leading and clearing lines should be recognised easily by a stranger; photographs or sketches, obtained from the point at which the leading or clearing marks first become useful, can help a great deal in this respect.

The transit indicating a leading or clearing line should always be reasonably sensitive. However, very distant or high back marks should be avoided if possible, since they may be obscured in haze or cloud.

24. Examinations

It is assumed that an indication of shoal water has been found, and followed up by interlining and cross lining, to reveal the need for a detailed examination of a comparatively small area.

Such an examination must be carried out on a scale larger than that of the main survey. A selection of the soundings obtained, always of course including the shallowest, may then be inserted in the appropriate place in the main work.

To carry out an examination properly the surveyor must be able to run very closely spaced lines of sounding; in extreme cases these may be as little as 10 feet apart on the ground. It is not necessary to fix at regular intervals, but an accurate fix must be obtainable whenever it is needed.

No two examinations are similar, and all provide scope for initiative and ingenuity on the part of the surveyor. The following sub-sections outline some of the methods which have been employed in the past, and may be used as a guide when deciding on the best way to tackle a particular problem.

a. Examinations; general technique

Examinations should be carried out on the largest practicable scale. A fresh 'sounding board' should always be used for the work, so that a clear picture can be built up as the examination proceeds. This new board might well in practice be a clear section of the normal scale board; it might be a brand new board showing just enough marks to obtain a suitable fix; it might be a mooring diagram, or even a sheet of squared paper carrying a lattice grid.

The absolute accuracy of positions plotted on an examination board may sometimes be of secondary importance; the positions of selected soundings can always be replotted on the normal survey scale, using the observed sextant angles or other fixing data. It is important, however, that relative positions should be accurately shown. In many cases some distortion of shape on the examination plot may be perfectly permissible; for instance curves of constant subtended angle may be drawn as straight lines, or a large scale tartan plot may be prepared if electronic fixing is being used.

The speed of the boat will have to be very slow. For this reason it will generally be desirable to run the lines up and down tide; on very large scales it may even be necessary to run lines in one direction only, against the tidal stream. Allowance may well have to be made for the facts that the observed sextant angles cannot be measured at a point, and the observers are not standing directly over the echo sounding transducers. It will be a great asset if the surveyor can obtain a delicate control of the movement of the boat in a particular direction, without the need to plot fixes; transits, fixed angles, and electronic devices can all be used to provide sensitive position lines.

If a variable speed paper drive is fitted to the echo sounder, one of the faster speeds should be used, as this will expand the trace and tend to make errors smaller.

Polaroid glasses and glass bottomed buckets can be very useful if the water is reasonably clear.

In all examinations it is most important that the surveyor should have available an accurately predicted tidal curve. If this tidal information is lacking he will be unable to recognise the true reduced least water when he finds it. It will be better still if tidal information can be signalled to him as the work proceeds.

When the shoalest point has been found by echo sounder, a hand lead should be dropped on to it, both to verify the least depth and to obtain a sample of the bottom. If a diver can be sent down, so much the better; he will be able to hold the lead on the shoalest point, collect a sample of the bottom, and, most important of all, bring back an intelligent description of what was there. His evidence will usually be conclusive, and it will always be most valuable.

If a diver is not available, or cannot work properly underwater due to strong tidal streams or poor visibility, it should be remembered that even the most thorough examination by echo sounder or lead may fail to detect the shoalest water, particularly when the bottom is composed of rock or coral. The surveyor should always bear in mind that in these circumstances it may be necessary to resort to sweeping.

b. Sextant examinations; enlarging the scale; starring round a pellet

In Fig. 3–45 it is required to examine the shoal *x*, which has already been fixed relative to the three marks *A*, *B* and *C*. The scale of the examination is to be double that of the original work. A new sounding board may be prepared, showing *A*, *B* and *C* on the larger scale, and large enough to embrace the new plotted position of the shoal. The following method is, however, simpler, and can generally be carried out in the boat on the original sounding board, using the simplest plotting instruments:

(1) Select any mark (*B* in this case) and produce radial lines from it through the other marks, and the plotted position of the shoal.

(2) Plot *A′* and *C′* on their respective lines, at double the distances *BA* and *BC* respectively. The shoal will move out to *x′*, where it will probably be clear of the work already on the board.

In the figure work on the original scale is shown in black, and green indicates the preparations for the examination. Reasonably small errors in plotting the new positions *A′* and *C′* will not affect the quality of the examination, since the new work will all be plotted using the same fix, and the important sextant observations fixing the shoalest water will be recorded, and can be replotted accurately if necessary.

Having prepared his new board, the surveyor lays and fixes the pellet, perhaps 50 to 100 yards inshore from the shoal, and in a position so that he can run transits on it against the background of the shore. It may be necessary to refix this pellet from time to time, particularly if there is a changing tidal stream.

He then proceeds to star round it in a methodical manner until the shoal has been thoroughly covered. The details of his plot are shown in the inset in the figure. Note how only the fixes at the ends of the lines have been numbered, the rest being self evident.

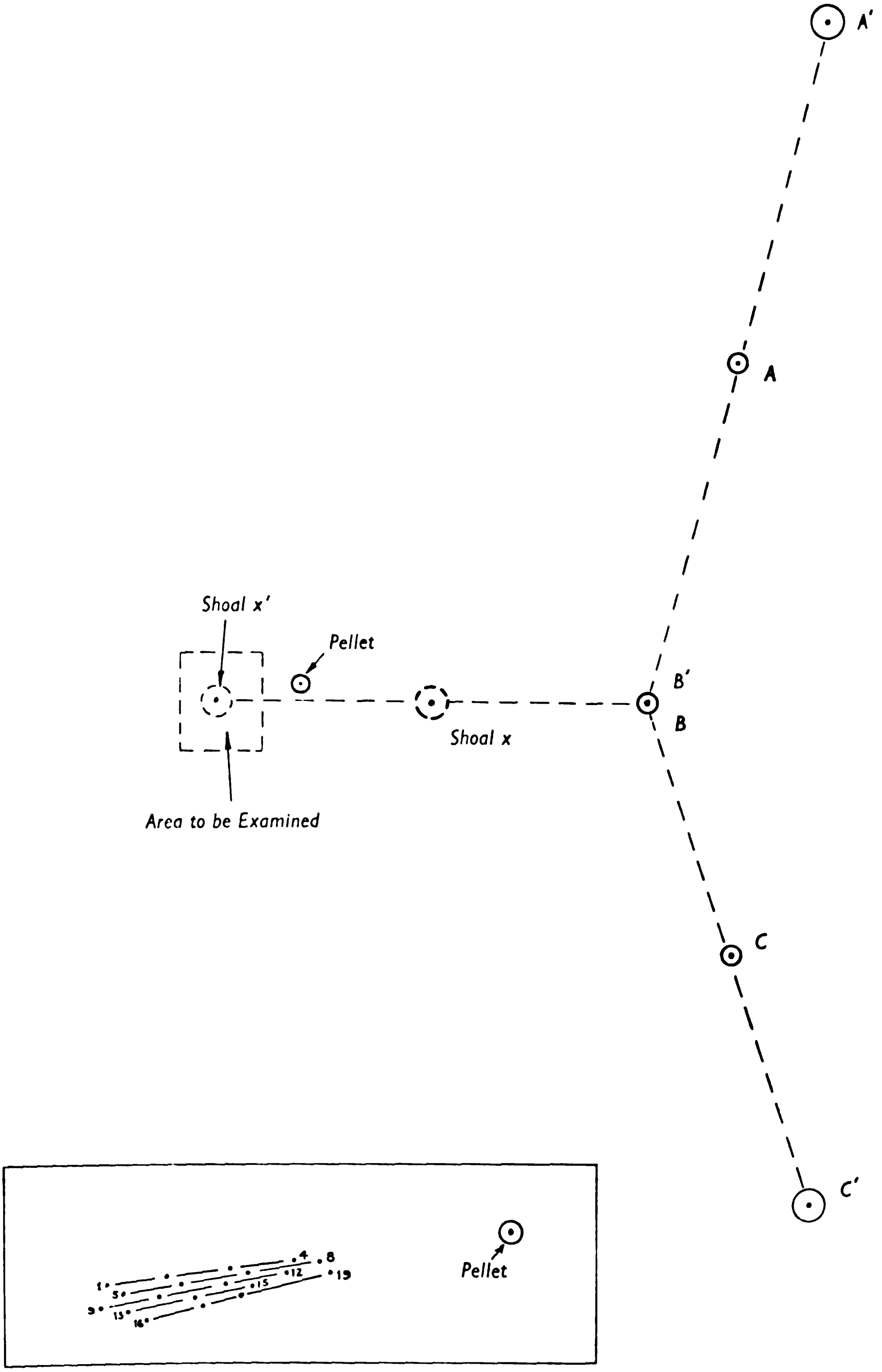
It is essential that the surveyor should acquire an accurate overall mental picture of the shoal before investigating individual peaks. Lines should not be run too close together to start with. The least depth found on each line should be reduced to chart datum by applying predicted or observed tidal heights. These least depths may be pencilled in on the board in their correct positions if desired. When, and only when, an overall picture of the shoal has been obtained, may the surveyor concentrate his attention on obtaining the least water. This may be done by interlining the existing examination lines, or by running closely spaced transits on the pellet, without fixing, and noting where the least water is obtained. The perfect examination is complete when the boat is stopped to obtain an accurate fix over the shoalest point, and the leadline depth agrees with that given by the echo sounder.

c. Examinations using fixed angles

Fixed angles can be most useful for examinations, particularly when the scale of the survey is small, or transits are insensitive. A large scale fixed angle plot may be constructed if desired (*see* Volume 1 and also Section 12 of this chapter), but it will generally be quite satisfactory to draw up a fixed angle tartan plot on a sheet of squared paper, assuming that the position lines are straight over the small area involved. The fixed angles themselves must of course be very sensitive if the scale of the examination is large.

The procedure, which is similar to that outlined in a and b above, is as follows:

(1) Choose a pair of marks which give sensitive position lines crossing the shoal at a broad angle to its longer axis. Using station pointers, plot three points on a position line crossing the middle of the shoal, measure the direction of the line



Detail of Plot

Fig. 3-45

joining them, and estimate the approximate courses in each direction, allowing for tide. Take off the limiting angles which bracket the shoal.

(2) Choose another pair of marks that give position lines crossing the first set at a broad angle. Measure the direction of these lines, and the cut off angles on each side of the shoal.

(3) A fixed angle tartan plot can now be prepared to any desired scale. It will usually only be required in complicated examinations.

(4) Run the lines along one or other of the groups of curves of constant subtended angle. One sextant angle should then remain steady on any one line, and provide delicate control similar to that given by a transit. Fixes should be taken and booked at normal intervals, and plotted if desired. With a little practice the surveyor will usually be able to visualise exactly where he is from a consideration of the observed angles alone. The least water obtained on each line should be reduced and noted, as in b above.

(5) When an overall picture of the shoal has been obtained, interlines may be run as necessary, and the least depth verified as in a and b above.

d. Examinations using electronic devices

Electronic devices may be used for examinations, provided they are sufficiently sensitive, and remain stable over the period involved. All fixed errors may be neglected if visual means are available to verify the position of the least water when it has been found. Tartan plots may be used. In simple cases it may be possible to dispense with plotting altogether, provided a careful written record is kept.

The general procedure is the same as that outlined in a, b and c above.

25. Management of a Sounding Boat

The efficient and proper management of a sounding boat is largely a matter of experience. Every boat sounder will pass through a stage of knowing what he ought to do, and yet being unable to do it; he should not be discouraged, as facility will only come with practice. Most young surveyors will be tempted at some time or other to 'push their fixes'. It is only too easy to plot a fix a little nearer to the planned line than it really is, in order to make the work look more imposing. Such a practice is not only dishonest, but self defeating, as it will blind the surveyor to his own deficiencies. It should never be resorted to. It will be far better to return to the ship with a set of honest, but crooked lines, rather than a set of dishonest and apparently straight ones.

a. Composition of a boat's sounding team

All sounding boats should have a capable and intelligent man as coxswain; a surveyor working in a boat handled by a bad coxswain may be likened to a man running in a race with a ball and chain secured to his leg. If, in addition to the coxswain, the boat carries a bowman, so much the better. He will be able to keep a lookout, take bottoms with the lead when required, and attend to the many little things which need doing from time to time. A modern engine should not require a man to tend it all the time; unfortunately some do, and this requirement may increase the boat's running complement to three.

The make-up of the surveying part of the sounding team will vary with the method of fixing employed. When sounding with the sextant and station pointer three men are required: the surveyor and his assistant to obtain the fix, plot it, and keep the record in the boat sounding book, and an intelligent man to attend to the echo sounder. On small scales when the fixing interval is long, the echo reader may be dispensed with if men are not easily available, but this should not be done unless there is no alternative.

When fixing by subtense or electronic methods the surveyor will generally need only one assistant, in addition to the normal boat's crew.

b. Speed of sounding; fixing interval

Fixes should be spaced about half an inch apart* on the sounding board. Their actual distance apart on the ground will depend on the scale of the work; the greater the scale the closer together they will be. Generally the fixing interval should be as short as possible, and the boats speed as fast as possible, so long as it does not exceed the bounds of prudence.

A beginner should not attempt to fix with sextant and station pointer more frequently than once every two minutes. With practice the fixing interval can be reduced to one minute. It is not possible to observe and plot a fix in much less than this time; however, on very large scales it is sometimes advisable to obtain fixes every half or quarter minute, and plot them when each line has been completed.

If electronic fixing is being used, it will usually be possible to reduce the fixing interval and increase the speed of the boat. Once more the boat's speed should be as fast as is prudently possible, provided the fixes are not more than about half an inch apart on the board.

c. Speed control; fixing at changes of speed

Whereas the speed of the boat can be varied whilst sounding, that of the echo sounder record paper remains fixed. The echo sounder trace is one of depth against time. If, as is always done, this trace is handled as though it were a plot of depth against distance, the speed of the boat must not be varied between fixes. When the surveyor has to reduce speed on approaching shoal water, or for any other foreseeable reason, he should always do so at a fix. If a sudden and unexpected reduction in speed is necessary, a fix should be obtained immediately. Speed should not be reduced gradually on approaching shoal water, but in definite steps; the fewer the number of these steps the better. Coxswains must be trained to resist their normal inclination to reduce speed gradually on approaching the shore, and whilst the surveyor is probably busy plotting the previous fix.

Increases of speed can, and should, always be made at a fix. When starting a line of soundings with the boat stopped, the order to 'fix and sound', should not be given until the boat is moving properly through the water.

If these precautions are not taken individual soundings may well be inserted incorrectly when the work is inked in.

d. Fixing on a particular fathom line

In channels or rivers it may well be important that a particular fathom line should be fixed with special accuracy, as it will form a danger line for shipping. In such cases the surveyor should endeavour to obtain a fix on or very close to this line each time he crosses it. He will not be able to do this unless he can refer to a reasonably reliable set of tidal predictions.

e. Erroneous fixes; use of one angle

Erroneous fixes will be obtained from time to time even in the best run boats. If they are recognised as such as soon as they are taken, they can be re-observed immediately, and no harm will result. In most cases the surveyor will get a rude shock when he plots, as the fix will not be consistent with its predecessors and the boat's known motion. A bad fix will be more easily detected if a regular fixing interval is employed, and no violent alterations of course are made.

Two alternatives are open to the surveyor who suspects the reliability of a fix:

(1) He may reject it entirely, marking it N.P. (Not Plot) on the echo trace and in his

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* Only in exceptional circumstances should they be more than three-quarters of an inch apart.

sounding book, and obtain another fix as soon as possible. This is probably the wisest procedure in most cases, or

(2) He may be able to say with certainty that one angle only of the fix is in error. In this case he should mark this angle N.P. in the sounding book, maintain his course and speed and, having obtained the next fix and plotted it, plot the lost fix with one angle on the known course line. The position line associated with this angle must of course cut the course line at a good angle for this 'half fix' to be of any use.

It often happens that a fix rejected in the heat of the moment can be made use of later in the calm of the lunchtime anchorage or the chartroom. All fixes marked N.P. should therefore be re-examined before the work is inked in, to see if anything can be made of them.

f. Keeping on the line by compass

On scales smaller than six inches to the mile most boat sounders use the boat's compass to control their progress along the planned lines of sounding. Running straight lines by this method is more of an art than a science, and practice is the only real way to become proficient.

The surveyor at the beginning of a line estimates the course to steer, and modifies it as necessary as he goes along. An experienced man will alter course to allow for a changing tidal stream before his fixes show this to be necessary, and maintain a straight line of advance over the ground. The beginner will very probably fall into the 'too much and too late' trap, and find his lines anything but straight; but perseverance will pay dividends.

The following points should be borne in mind:

(1) To be of any use the compass must be mechanically and magnetically sound. It need not be fixed permanently in the boat, but there must be some means of assuring that its lubber's line is parallel to the fore and aft direction. The coxswain must be able to read it comfortably from his steering position.

(2) It is a good plan, when starting work in a new area, to estimate the course that will hold the boat on the planned lines, and run the first line on this course, making no alterations whatsoever. Very probably the line will neither be straight nor run in the required direction; but the surveyor will gain valuable information concerning the behaviour of the tidal streams and the boat, which should enable him to run his next line (the first one that really matters) with accuracy and confidence. If large deviations affect the boat's compass, it will be prudent to carry out this procedure in both directions.

(3) In theory alterations of course should only be made at fixes. In practice most surveyors alter course as soon as the need to do so becomes apparent, and between fixes if necessary. This is quite permissible so long as the alterations are not too violent. The criterion to be applied is that the plotted track must at all times faithfully represent the boat's actual movements. There is usually not much point in making alterations of course of less than 5°, since the accuracy of the steering is not likely to be better than half this value.

(4) The surveyor must make certain that his coxswain gets on to a new course as soon as he orders it, and stays on it.

(5) In a tideway, course must be altered at the point where from experience, or even intution, the surveyor knows that the stream changes its rate or direction, and before the fixing shows that an alteration is necessary. It should always be remembered that the plot on the sounding board is usually at least half a fix behind the boat's true position.

Fig. 3–46 shows how a beginner might sound a long a planned line, which is shown pecked. He has estimated the course to steer, and positioned himself at the beginning of the line, either by obtaining trial fixes or by running along one sextant position line until the other angle comes on.

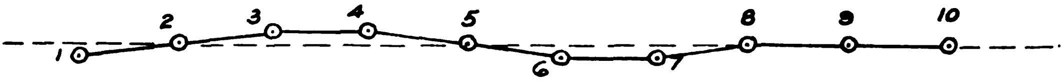


Fig. 3–46

On plotting fix 1 he very rightly maintains his course. At fix 2 he is not quite sure whether to alter course 5° to starboard or not. In the event he does not. Fix 3 finds him off to port slightly, so he makes an alteration of 10° to starboard. At fix 4 he can see that this alteration is having the desired effect, since he is the same distance off the line as he was at fix 3. Finding himself back on the line when he plots fix 5 he alters course 5° back to port, but to his dismay finds that this alteration has little or no effect, since at fix 6 he is off to starboard. Then he realises his mistake: when he plotted fix 5 the boat was actually nearly three-quarters of the way on to fix 6, and his alteration had no time to take effect before he fixed again. He should have made his alteration to port as he obtained fix 5, and not waited to plot. Having plotted fix 6, he alters back to his original course at 1 fix, and this time alters 5° to starboard as he obtains fix 8. From this point on he has no more trouble.

g. Keeping on the line using natural transits

On scales larger than about six inches to the mile it will not be easy to run straight lines by the compass method described in f above. Unless the scale is very large and the area to be sounded comparatively small, the erection of artificial transits for each line will usually be out of the question. With practice, natural transits can be picked out, which will provide delicate control to keep the boat on the various planned lines of sounding.

When using natural transits the coxswain of the boat becomes all important. It is essential that the surveyor and his coxswain should work together for some time, so that they may become used to one another. An apt and experienced coxswain will usually be able to pick his transits for himself, thus saving a great deal of time. On the other hand some otherwise perfectly capable men can neither recognise the right transit when it is pointed out to them nor run along it without constant supervision; they should be employed elsewhere.

(i) Shooting up and running a transit from seaward. When sounding with transits the first line should always be run from seaward. The procedure is as follows:

(*a*) Obtain trial fixes and manoeuvre the boat until it is on the first line at its outer end. Stop the boat relative to the ground. This may be done by watching two natural transits which cut at a broad angle.

(*b*) Obtain a fix, plot it, and take off from the board, with station pointers, the angle between a convenient sounding mark and the direction of the line. The mark should be on or near the coastline, and the angle should be small, if errors are to be reduced as much as possible.

(*c*) Set this angle on the sextant, check that the boat has not moved, and sight the references sounding mark. The reflected or direct line of sight, depending on whether the mark is left or right of the line, will be along the first sounding line. The surveyor must select two natural objects which form a sensitive transit for this line; they might well be a bush or a patch of weed on the high water line, and a break in the trees on the skyline.

(*d*) These two objects must now be pointed out to the coxswain of the boat. If there is any doubt a little extra time spent over this will never be wasted. If the coxswain can look through the sextant himself, so much the better.

(*e*) Before moving away the surveyor should select a front mark for his second line, which will be run out from the beach; he can do this by estimating the known distance between his lines along the foreshore. If he can select a back mark to go with it, in the same way, he should do so.

(*f*) The boat may now proceed to seaward a little, get on the transit, and run in along it. As soon as he is satisfied that the coxswain is handling the boat correctly, the surveyor may start to fix and sound. In theory all his fixes should plot exactly on the planned line. In practice they probably will not, but the course made good will be reasonably straight. Small adjustments to the transit may be necessary as the boat proceeds. The coxswain should note the compass course which holds the transit. This knowledge will be valuable when the second line is run out from the shore.

(*g*) After a while the original back mark will probably disappear over the skyline. The coxswain should select a closer object in line with it before it does so, steering on it, and changing again as many times as is necessary. When the boat arrives off the beach the original front mark may well be only a few yards nearer than the last of the back marks selected in this way.

Distant back marks make transit sounding easier, since one mark can be used for several lines, which will still be virtually parallel.

(ii) Running a back transit from inshore. If the surveyor has made the correct preparations, as outlined in (i) above, he will be able to place the boat opposite the front mark for his second line, and to estimate the course to steer along it.

Assuming that all reasonably distant back marks, including the one selected in (i)(*e*) above, are out of sight over the skyline, the procedure is as follows:

(*a*) Place the boat opposite the new front mark. Check her position with a fix. Adjust position if necessary to get exactly on the line, changing the front mark slightly to conform.

(*b*) Set off on the estimated course for the line, with the coxswain glancing at the front mark fairly frequently. He will soon be able to pick up a transit that corresponds to the course being steered. As soon as he has, he should hold it. It is extremely difficult to steer a boat steadily whilst looking over the stern; the coxswain should therefore steer primarily by compass, and adjust his course as necessary to hold the transit, which he should glance at fairly frequently.

(*c*) The transit selected in (*b*) will probably be comparatively insensitive, and it will become more so as the boat proceeds to seaward. It is quite likely too that it will not take the boat in exactly the required direction. It must therefore be modified as the boat proceeds, and in the light of the plotted fixes. The front mark will of course remain fixed, whilst the back mark is changed, always being as far back from the beach as possible.

(*d*) Sooner or later the back mark selected in (i) (*e*) will appear over the skyline; it should, if everything has been done properly, be in line with both the marks forming the current transit.

Running back transits from the shore is not easy. The vital period is that between the start of a line and a position one or two fixes to seaward. It should be the surveyor's aim to get the provisional back transit right as soon as possible. His task will be much easier if he is blessed with an intelligent and capable coxswain.

h. Keeping on the line using Decca

If the survey area is within the coverage of a navigational decca chain, a decca receiver may be used to keep on the lines, even though it may not be used for fixing. The decometer unit should if possible be placed so that it can be read conveniently by the coxswain from his steering position.

After a little practice it becomes almost second nature to steer by decca. Some surveyors construct small mechanical indicators to help the coxswain to remember whether to alter course to port or to starboard if the decometer indicates that he is off the line. However, if the decometer itself is used intelligently there is no need for these additional aids.

Suppose, for instance, that the decometer reading is smaller than it should be. The coxswain knows at once that he must steer the boat into a region where the decca readings are greater; he may have to alter course to port or to starboard, depending on which way he is going, but the true direction, e.g., north-west, in which he must move, will remain constant for any particular pattern.

At times local shifts in a decca pattern, caused by skywave or land effects, can lead the unwary boat sounder off his intended line, particularly close inshore or near an uncovered bank.

i. Additional information to be collected by the boat sounder

Although his primary task is sounding, the boat sounder must devote some of his time to other things if the chart he is helping to make is to be complete.

(i) Fixing visible dangers. Visible dangers, such as drying rocks and wrecks, should be fixed by the boat sounder. He should ensure that there is little possibility of any of them lying undetected by inspecting the area concerned at low water springs.

When fixing these objects it will be best, provided it is possible, to shoot them up by steaming round them and obtaining a sextant fix as they come into transit with each of the three marks being used for the fix. This method provides a check on the fixing, and the result is more reliable than that obtained from a single fix at the object.

(ii) Fixing aids to navigation. All natural and man-made aids to navigation must be fixed. On anything but the smallest scales, buoys should be fixed on the flood and ebb streams and a mean position accepted. It should be remembered that light-vessels can, and sometimes do, lie to an extremely long scope of cable; the position of their anchors is required.

The characteristics, shape, and colour of buoys, beacons, and light-vessels must be noted in the field, and not taken for granted.

(iii) Noting the coastline. Very often it is wise for the boat sounder to make notes on the coastline, when he is at the inshore ends of his lines, and sketch the position of the high water line on his sounding board. On small scales most of the coastline can be surveyed from the boats in this way, enabling the separate coastlining party to concentrate on delineating details which require the presence of a man on the shore. When the coastline is being taken from aerial photographs, the boat sounder's sketch and notes can be most useful in helping to interpret difficult sections; if he can take the relevant photographs with him and interpret them with the area they depict before his eyes, so much the better.

(iv) Obtaining samples of the bottom (*see* Part 7 of this chapter). It is usual to obtain most samples of the bottom with an armed lead, and a few with a dredge or other device which collects more material. Dredging operations cannot ever be combined with sounding, although it is quite possible to break off sounding from time to time to carry them out.

When the scale is small and the water is shallow it will generally be best to obtain bottom samples with the armed lead concurrently with the sounding. They should be obtained about one inch apart in all directions, on the scale of the survey.

On large scales, or when the water is deep, it will usually be wisest to obtain bottom samples after a particular area has been sounded out.

j. Sounding in special circumstances

Whilst the principles of boat sounding are always the same, their application can be varied to suit particular circumstances. The following notes are not all embracing, but being the result of experience, may be helpful.

(i) Sounding in a river. When sounding across a river the surveyor must be on his guard against displacing his inshore soundings towards the middle of the stream; this will probably happen if he starts to sound at the beginning of his lines before the boat has gathered way properly, and slows down too soon as the bank is approached. Very careful speed control is necessary (*see* Section **25c** above). Fathom lines which weave in and out once every two lines should be regarded with suspicion. A carefully controlled line or two run parallel to both banks will provide a good check on the main work. There is no reason why the main lines should not be run up and down stream, if sounding across is very difficult; but in this case a few cross lines should always be run as a check.

(ii) Sounding in an estuary. In an estuary the salinity of the water may well vary very appreciably during the course of a few hours; it will usually be salt on the flood stream, and may be almost completely fresh at the last of the ebb. The surveyor must therefore pay particular attention to matching the speed of his echo sounder properly to the velocity of sound in water. In extreme cases it may well be necessary to carry out a bar check every hour or so. In one particular estuary in Borneo the neglect of these precautions would have introduced an error of over two feet in eight fathoms.

(iii) Interlacing of sounding lines. If for any reason the best fix available is not very strong, it will be a good plan to interlace the lines of sounding. The method consists of running the lines at double the normal spacing, and then 'interlining' to fill in the gaps. The resulting lines will be mutually supporting, and errors of position will tend to show up if they are of any magnitude.

(iv) Sounding on very large scales. When the scale is so large that the length of the boat is more than about 0·1 inches on the plot, special precautions must be taken. If possible the work should be controlled by one angle only, and a transit. If two angles must be measured the observers must stand literally nose to nose. Allowance must be made for the distance between the observing sextant and the echo sounder transducers. In a tideway the observer may be on a transit, but the transducers may be off it, due to the cant of the boat. It may well be necessary to allow for the fact that the fixing objects are elevated. The echo sounder paper speed should be as fast as possible, and the fixes must be marked on the paper with special care.

k. Fixed angle sounding

In rivers and estuaries where constant resurveys are necessary to follow the changing pattern of the sea bed, fixed angle sounding has much to recommend it. The boat follows a curve of constant subtended angle, altering course continuously by small amounts to do so, and obtains a fix by combining any suitable sextant observation with the fixed angle. A very delicate control over the boat's track is obtainable, provided the fixed angle is sensitive.

Fixed angle sounding is not recommended for general use, since the preparation of the lattices takes a long time, and the surveyor is limited in his choice of fixes to those which have been pre-plotted on his board.

The preparation of fixed angle plots is described in Volume 1, Chapter 6, Part 2. *See also* Sections **12** and **24c** of this chapter.

26. Management of the Ship when Sounding

Anyone who has served his apprenticeship in the boats will have no difficulty when his time comes to sound in the ship. Indeed, he is almost certain to find that it is a great deal easier. The greater height of eye, steadier platform, greater speed of advance, and the use of a gyro instead of a magnetic compass, all tend to make the problem of keeping on the planned line much simpler.

Where the points discussed in Section **25** above are relevant, they apply equally well to ship sounding.

The surveyor sounding on the bridge must have the safety of his ship uppermost in his mind the whole time. A ship cannot stop in a few yards; neither can she turn about in her own length. The temptation to run the ship lines just that little bit nearer to the coast, or to investigate a shoal sounding in her, should usually be strongly resisted. Allowance must always be made for the ship's advance as she turns, particularly at the inshore ends of the lines; her hull will be most vulnerable to damage at the point where she is beam on to the coast, and therefore nearest to it.

Where the ship and boats are working together, as in the north-eastern part of the area depicted in Fig. 3–42, it is a good plan to run the boat lines first, if this is possible. The ship will then always be turning in sounded water at the ends of her lines.

The prudent ship sounder will always select a particular fathom line, inside which he will not proceed without very careful thought indeed.

It is sometimes necessary in a surveying ship to accept a much higher than normal risk of running aground; for instance, a vital task may have to be carried out in conditions in which it would be unsafe to put a boat in the water. In these circumstances the work should be carried out on a rising tide, as soon as possible after low water; only in the direst necessity should the risk be run of going aground at or near the top of the tide, or when it is falling.

27. Formation Sounding

It may be convenient, when more than one ship or boat is available, to sound in formation. This method is generally employed on fairly small scales, e.g., 1/50,000 or smaller, when only one of the vessels can fix. A ship sounding in formation with her boats will usually cover the ground more quickly than she will by herself. For instance, suppose that the ship and two of her boats can sound in formation at six knots, then to cover the same amount of ground in the same time the ship by herself would have to proceed at 18 knots.

The procedure is as follows:

(*a*) The satellite vessels station themselves on either beam of the master vessel, at distances equivalent to the intervals between the lines of sounding. There may be several of them, but if there are more than two the system becomes rather unwieldy. They maintain station by observing relative or true bearings and distances from the master vessel. Masthead angles, horizon dip, and radar are very convenient methods of measuring distance; if a gyro compass is not available, bearing is best held visually on, say, the transit of two sampson posts on the master vessel.

(*b*) At each fix the master vessel fixes herself, and obtains gyro bearings and horizon dip or radar distances into all the satellites.

(*c*) All the plotting is carried out in the master vessel.

(*d*) Records are kept separately in each individual craft; great care is necessary to ensure that they do not become muddled.

(*e*) Good communication between the various vessels is essential, both for controlling the fixing, and manoeuvring. Reliable radio telephones are best, but perfectly adequate control can be provided with flag hoists. Very often it is a good plan to control the fixing visually in any case, and reserve the radio telephone for general instructions and manoeuvring orders; a well drilled team using this method can proceed for long periods without any verbal exchanges being necessary.

28. Records to be kept whilst Sounding

No hard and fast rules can be laid down concerning the records which should be kept whilst sounding, beyond saying that they must be clear, concise, and complete. The following notes on the records normally kept in the Surveying Service of the Royal Navy may be used as a guide.

a. The sounding board (*see also* Volume 1, Chapter 6, Section **25a**)

Fixes are plotted on the sounding board as the work proceeds, using a fairly hard pencil. They should be numbered consecutively, and joined by a line representing the vessel's track; Figs. 3–44 to 3–46 show what is required.

Most of the additional information referred to in Section **25 i** above can conveniently be plotted on the board as it is obtained.

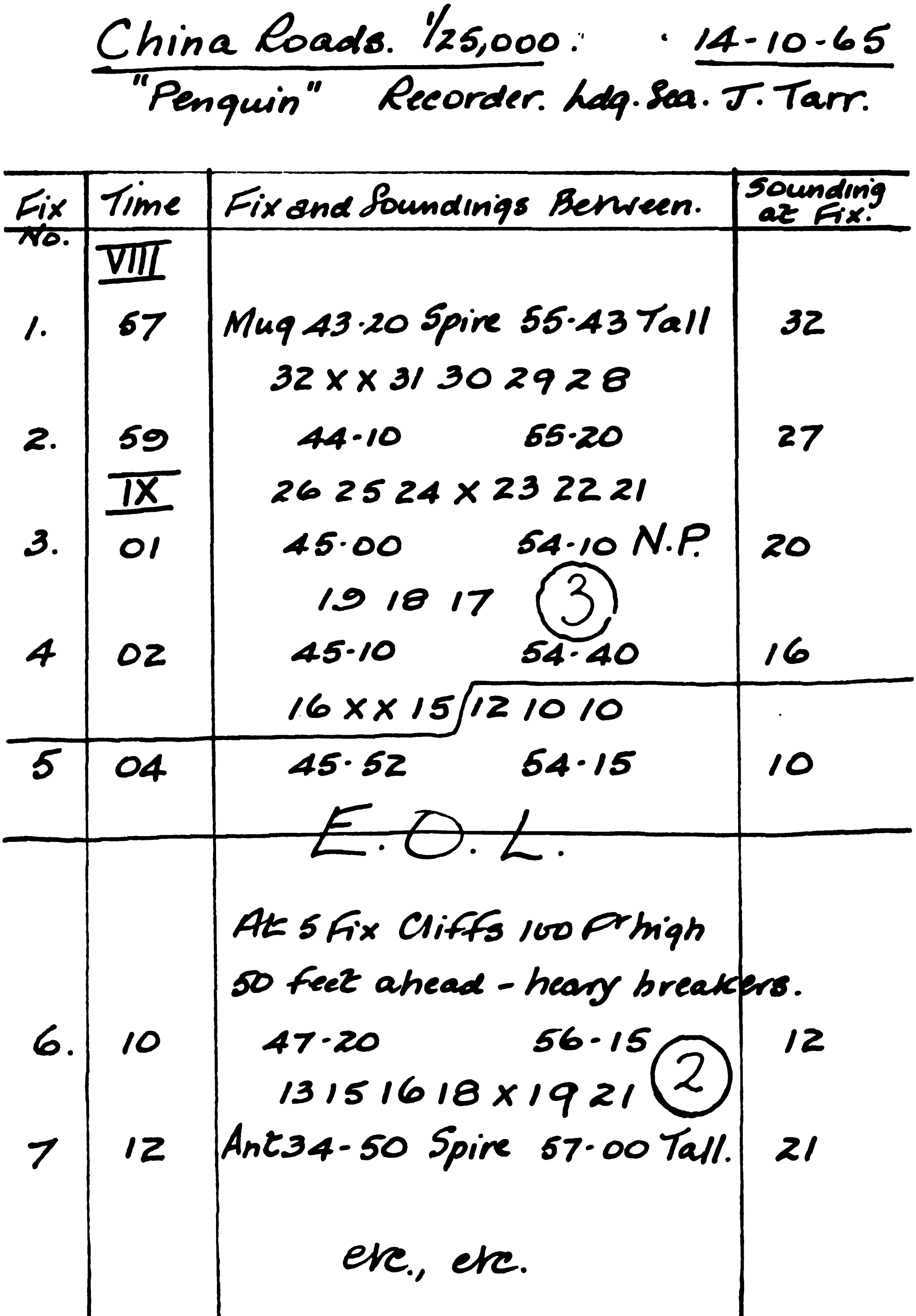
All this work is inked in on completion of a day's sounding. It is a good plan to use different colours for each day's fixes and the lines joining them, and to add a colour index; this procedure makes any subsequent cross checking or investigation much easier. Additional information, such as the coastline or buoys, is best inked in with black ink. There is no reason why the sounding board should not carry notes or sketches, if they will be helpful; these should be inked in at the end of the day with the rest of the work.

Where an area is regularly being resurveyed, it is sometimes convenient to face a sounding board with a sheet of thick opaque stable plastic, the latter being a replica of part of the plotting sheet. This board is then covered with a sheet of transparent plastic, on which the plotting is carried out. The basic sounding board may then be used many times over. Care is necessary to prevent relative movement between the two layers of plastic.

b. Boat sounding books

Boat sounding books, which are issued personally to all surveyors, must contain a complete record of all the observations obtained. It is usual to record the time of each fix to the nearest half minute or minute. If an echo trace is being obtained, the sounding at each fix should be entered in the book; when non-recording echo sounders or lead-lines are being used, all soundings must be noted in sequence. The letters N.P. (Not Plot) and E.O.L. (End of Line) are entered when appropriate. Full details of all bar checks and other calibrations must be noted. When the tidal observations for the day have been obtained, reductions to the soundings should be entered in colour. All these details may be recorded in pencil.

Fig. 3–47(a) shows a typical page from a boat sounding book. It records the work between 0857 and 0912. The right-hand angle at fix 3 was observed incorrectly, and is therefore marked N.P. The crosses indicate that a sounding is the same as the previous one. Note that seven soundings are being recorded between fixes; this is usually reasonable; in any event an odd number should always be chosen, as this makes inking in simpler. With the fixes two minutes apart soundings are being noted every 15 seconds. If the echo sounder is of the recording type, the soundings between the fixes may be omitted. The tidal reductions (in red) are entered at the end of the day's work. If the echo sounder has an index error this should also be noted, and applied with the reductions.



China Roads. 1/25,000. · 14-10-65
"Penguin" Recorder. Ldg. Sea. J. Tarr.

Fix No.	Time	Fix and Soundings Between.	Sounding at Fix.
	VIII		
1.	57	Mug 43·20 Spire 55·43 Tall	32
		32 X X 31 30 29 28	
2.	59	44·10 55·20	27
	IX	26 25 24 X 23 22 21	
3.	01	45·00 54·10 N.P.	20
		19 18 17 ③	
4	02	45·10 54·40	16
		16 X X 15 / 12 10 10	
5	04	45·52 54·15	10
		E.O.L.	
		At 5 Fix Cliffs 100 ft high 50 feet ahead - heavy breakers.	
6.	10	47·20 56·15 ②	12
		13 15 16 18 X 19 21	
7	12	Ant 34-50 Spire 57·00 Tall.	21
		etc., etc.	

Fig. 3-47(a)

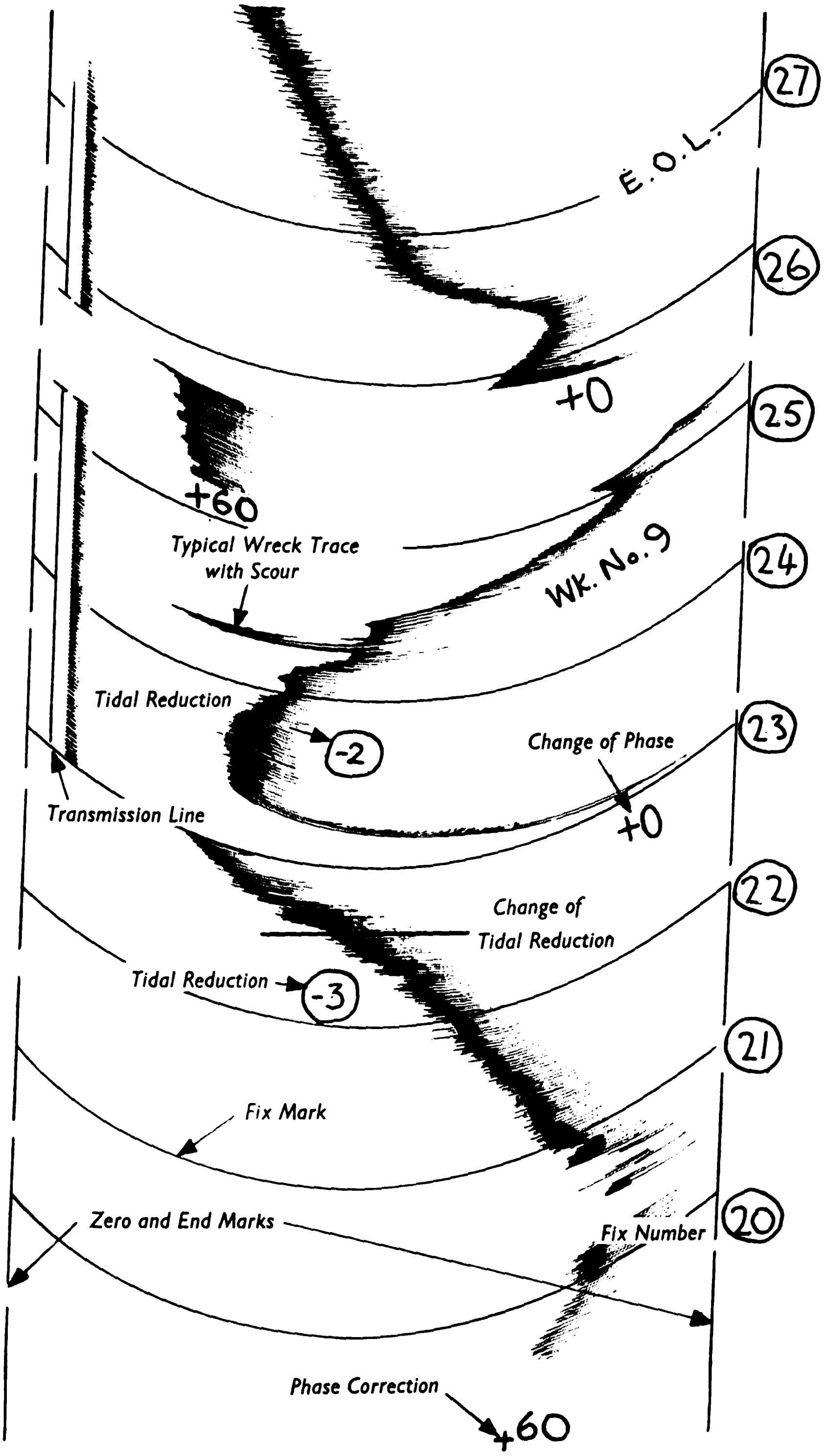

27
E.O.L.
26
+0
25
+60
Typical Wreck Trace
with Scour
Wk. No. 9
24
Tidal Reduction
-2
Change of Phase
23
+0
Transmission Line
22
Change of
Tidal Reduction
Tidal Reduction
-3
21
Fix Mark
Zero and End Marks
Fix Number
20
Phase Correction
+60

Fig. 3-47(b)

c. Deck books

The sounding book used in a ship is known as a deck book; it is usually larger than a boat's sounding book, and may in fact be used to record all types of information gathered on the bridge or deck of a ship.

Deck books used for sounding must contain a record of all observations relevant to the work in hand. These observations should be entered in the way described in a above; since the deck book is much larger than a sounding book they may be spread out more than those shown in Fig. 3–47(a).

For ship work it is usual to have separate deck books for odd and even days, so that whilst one is in use on the bridge the other may be referred to in the chartroom.

d. Echo sounder traces

The echo sounder trace forms an important part of the sounding record. It must therefore be handled with great care. Dry recording paper is relatively robust, and the record on it is stable; so long as it is kept dry, it should give no trouble. Damp potassium iodide paper should be dried as soon as possible after the record has been made on it, kept in a subdued light, and above all protected from the direct rays of the sun. If it is exposed to sunlight the trace will almost certainly be bleached, and disappear entirely. If a potassium iodide trace is rolled too tightly before it is dry, the various layers may print out on one another, confusing the record.

As the sounding proceeds the echo trace should be marked with the fixes and their numbers, the current phase of the machine (this is important, and can easily be forgotten), and any relevant notes such as N.P., E.O.L., or a note indicating a change of boat's speed between fixes. A typical trace is shown in Fig. 3–47(b). At the end of each line, or more frequently if the lines are very long, the fix numbers on the sounding speed between fixes. A typical trace is shown in Fig. 3–47(b). At the end of each that they agree. Any discrepancy should be resolved immediately. It is a good plan to note details of the results of bar checks or speed checks on the echo trace as well as in the sounding book.

At the end of a day's work the trace should be labelled so that it can easily be identified and related to the plotted work on the board and the relevant part of the sounding book; the marking should be on the echo paper itself, and not on a separate sheet. Tidal reductions and echo index errors should be noted on the trace before the soundings are inked in.

Part 4 The Reduction and Inking in of Soundings

29. The Reduction of Soundings

Soundings obtained in the field must be reduced to a standard reference plane, by subtracting from them the height of the tide at the time they were taken. Where the water is very deep, or the work is more of the nature of a reconnaissance than a thorough survey, or where it is impossible to observe the actual rise and fall of the tide, reductions may be taken from a curve plotted from the predicted times and heights of high and low water. This method has the inherent drawback that the predictions may or may not be correct in themselves, and will certainly not take into account possible quite large variations in water levels caused by wind and weather.

For all important work the rise and fall of the tide in the survey area should be observed on a tide gauge or pole whilst sounding is being carried out. It will then be possible to plot a curve showing the actual variation in the water level, and to reduce the soundings to a suitable reference plane. If a co-tidal chart of the area is available it will generally be prudent to apply time difference corrections and height factors to the observed tide pole readings.

This reference plane is known as the Sounding Datum for the area concerned. It is desirable that it should approximate to the level which will finally be chosen for Chart Datum in the area (Chart Datum is usually, but not always, very near the level of Mean Low Water Springs), but there is no need for the surveyor to go to extreme lengths to ensure that the two datums will agree exactly. The important thing is that the sounding datum selected in the field should be sensible and practical, and that it should be very firmly connected by levelling to bench marks ashore. It will then be a simple matter for the tidal experts and cartographers in the office to apply corrections to all the soundings on the fair charts or final tracing, if they wish to refer them to a datum different from that used by the surveyor (*see* Chapter 2).

a. The tidal reduction curve; obtaining and applying reductions

Fig. 3–48 shows a typical tidal reduction curve. It has been drawn from observations obtained every half hour, with additional readings either side of high water. The horizontal lines cutting the curve have been added by the surveyor, to enable the reductions to be read off and noted in the form of a table. Long standing tradition rules that no reduced sounding should be too deep by much more than a quarter of the unit employed, on account of errors in reduction; reductions in feet therefore change at every 0·3-foot level.

Consider the part of the curve between 0932 and 1040; the reduction for this period is seven feet. At 0933 the actual height of the tide is just over 6·3 feet; a sounding obtained at this time will have seven feet subtracted from it, and will therefore be inked in as being nearly three-quarters of a foot less than it really is. At 1036 the actual height of the tide is 7·25 feet, only a quarter of a foot more than the reduction in use; a sounding taken at this time will therefore be shown only very slightly deeper than it really is.

Reduced soundings of less than one foot are considered to be 'awash'. When the reduction is greater than the observed sounding, the difference is shown as a drying height (always quoted in feet) above sounding datum.

In the Hydrographic Service of the Royal Navy soundings are shown in feet, or fathoms and feet, up to and including a depth of 11 fathoms reduced. Reduced depths greater than this are quoted to the nearest fathom, the dividing line being at the four-

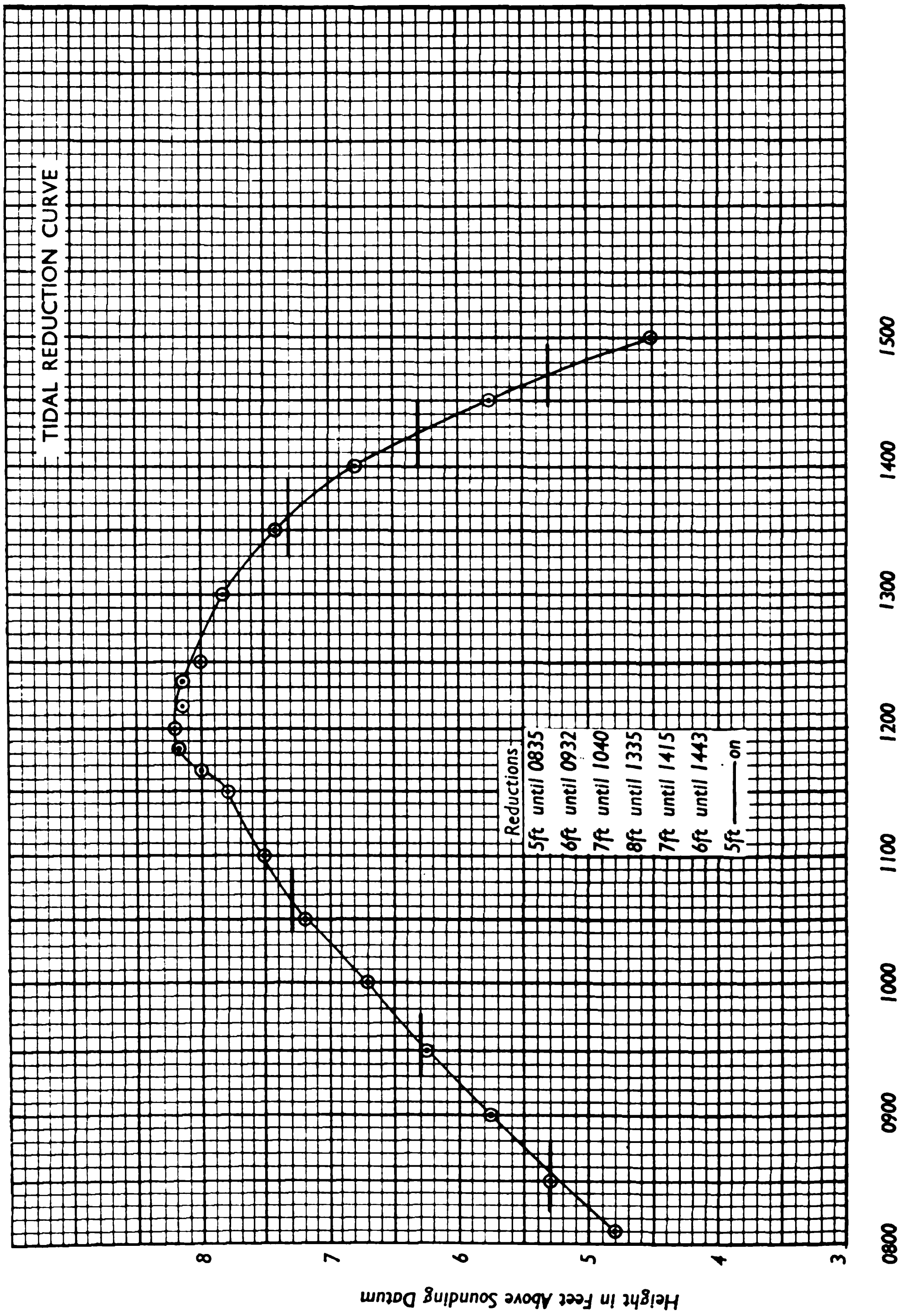

TIDAL REDUCTION CURVE
Reductions
5ft until 0835
6ft until 0932
7ft until 1040
8ft until 1335
7ft until 1415
6ft until 1443
5ft —— on
Height in Feet Above Sounding Datum
3
4
5
6
7
8
Time
0800
0900
1000
1100
1200
1300
1400
1500

Fig. 3-48

foot mark in each fathom. Thus reduced soundings of 66, 67, 68, 69 and 70 feet would all be inked in as 11 fathoms; soundings between 71 and 76 feet inclusive would be shown as 12 fathoms, and so on.

30. Preparation for Inking In

a. Preparing the sounding board

On completion of a day's work the fixes and the lines joining them should be inked in on the board. It is a good plan to use coloured inks for this purpose, a different colour being used for each day. A table showing the dates on which soundings were obtained, and the number of fixes taken, should be built up in one corner of the board as the survey progresses, using the same inks as those used to show the fixes themselves. This procedure will make any subsequent checks or investigations much simpler.

The sounding tracing should be fitted over the board, and held down with weights.

In some cases it may be more convenient to dispense with the sounding tracing, and ink in the soundings directly on the board. The board then requires no preparation before the work is carried out. This procedure is not recommended for general use, since the fixes become lost under the ink figures, and it is difficult later on to find them if they are wanted.

b. Preparing the echo trace and sounding book

Damp potassium iodide paper shrinks considerably as it dries. Since most scales used whilst inking in are calibrated to fit the record in its dry state, it will generally be necessary to dry it thoroughly before inking in. It may of course be used in its damp state with a scale similar to that fitted on the machine itself. It is dangerous to try to read soundings off a trace when it is half dry, as it will probably then not fit any scale that is carried. If zero and end marks have been recorded (*see* Fig. 3–47(b)), the surveyor should ensure that they fit the scale being used, throughout the length of the trace.* If they have not, the reading scale may be checked against the transmission line and the depths at the various fixes, which will have been noted in the sounding book.

Dry paper is relatively stable, and is very unlikely to distort after it has been used. The prudent surveyor will nevertheless still check that his reading scale does fit correctly between the zero and end marks, or between the transmission line and the recorded depths at the fixes.

The echo trace comprising a day's work may well consist of several pieces. These must be joined together into one continuous roll (Sellotape is very useful for this), one end of which should then be labelled in the way described in Section 28d above.

The tidal reductions (*see* Fig. 3–48) are entered on the echo trace and in the sounding book, in coloured pencil, together with the index error of the echo sounder if it has one.

31. Echo Reading Scales; the Trace Reader

Engraved scales are provided with most recording echo sounders used in surveys, which fit the paper in the condition in which it will be when the inking in takes place. Care is necessary with damp paper sets not to get them muddled with those intended for the machine itself. Soundings may be read off a trace using one of those scales, which should be fitted between the zero and end marks if these have been recorded, or between the transmission line and the depths recorded at the various fixes. Where the transmission line does not record, i.e. when the phase is anything but zero, common sense must be used.

The use of a trace reader is recommended, if one is available, as it makes the task of inking in quicker, simpler and more reliable. The type used in the Surveying Service of the Royal Navy is illustrated in Fig. 3–49.

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* Sometimes a scale may 'just not fit', whatever is done. If this happens common sense must be tempered with caution. It may be wise to book all the soundings, as they are obtained, to provide an additional check.

Referring to the figure, the most important parts of the machine are as follows:

(1) Two sets of spring loaded rollers, *A* and *D*, through which the echo trace is threaded, and by means of which it may be fed in either direction across the bed plate. They are connected by a chain drive, and operated by turning the knurled knob *K*. The paper may be released by taking the tension off the rollers with the two levers marked *B*.

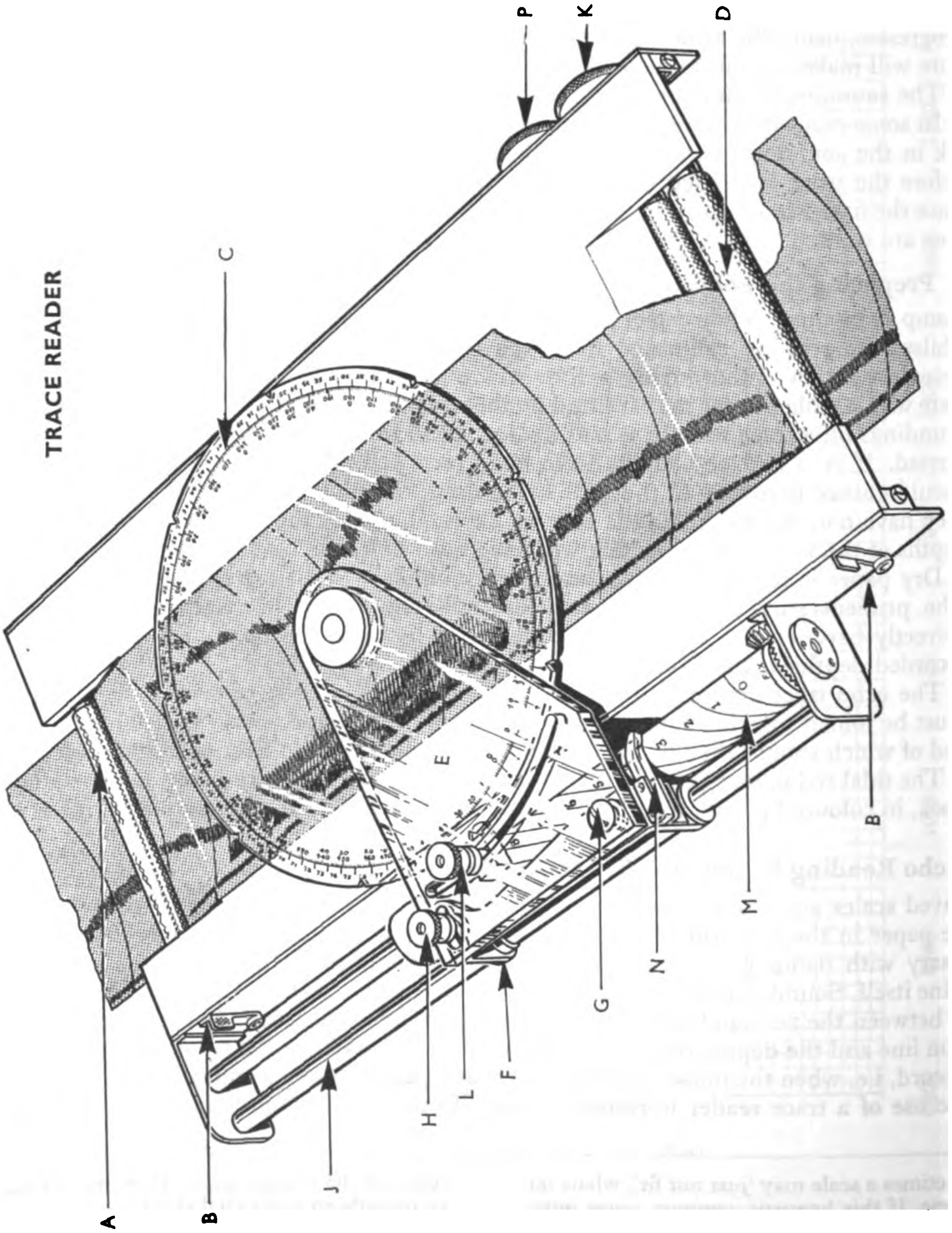

Fig. 3–49

(2) A circular reading scale *C*, which may be changed to suit the echo sounder being used. It is graduated (in black) in feet and fathoms in an anti-clockwise direction from its zero mark, and in feet (in red) in a clockwise direction from this same mark. The scale may be rotated about its pivot on the carrier arm *E*, but is normally held in one of several positions, which correspond to the various phases of the echo sounder, by a spring loaded ball catch under the knob *L;* this engages in the vee slots cut in the circumference of the scale. The tidal reduction is set by moving the scale clamping knob *L*, together with the ball catch, in the curved slot in the carrier arm, until the reduction required (red figures) coincides with the zero mark on the trace; reductions are then applied automatically.

Before using the machine it is important to check that the scale fits the trace properly (*see* Section 30b above). This check should be repeated from time to time as inking in progresses. It is also important to ensure that the zero mark on the trace does remain under the set tidal reduction, as the trace is moved backwards and forwards with the rollers; slight misalignments of the latter, or damage to the edges of the paper, can cause it to wander quite appreciably.

(3) The carrier arm *E* is attached to the sliding carriage *F* by the bolt *G* and knurled nut *H*. It may be pivoted about *G* until the curvature of the graduations on the scale fits exactly over a fix mark, and then locked in position by tightening *H*; this ensures that the scale and the markings on the trace are concentric.

(4) The carriage *F* slides along the brass rod *J*, taking the scale with it, so that several inches of echo trace can be examined without moving the paper. It can also be hinged back on *J*, lifting the scale clear.

(5) A scroll spacing device is fitted to the machine. The cylinder *M* may be turned by the knurled wheel *P* until the distance between the datum fix line and any desired scroll line corresponds to the distance on the trace between fixes; movement of the carriage *F* so that the pointer *N* coincides with each scroll line in turn will produce a number of soundings spaced at the required interval. In the figure the device is set to produce three soundings between the fixes. In most cases it will be quite satisfactory if the spacing of soundings is judged by eye; the scroll spacer is likely to be of most use if a large number of soundings are required between fixes.

Trace readers are not at present (1965) available in the commercial market. They can, however, be constructed by any competent craftsman.

32. Inking In

A great responsibility devolves on the surveyor who inks in a day's work, often at a time when he himself is physically weary after a long day in the boats or on the bridge. The depths and fathom lines he inserts on the sounding tracing must faithfully represent the topography of the sea bed. His figures must be easily read and yet not be too large; shallows and deeps must be equally well shown; no real shoal sounding must ever be omitted, and yet it and its neighbouring soundings must not be displaced appreciably in order to show it.

Good inking in is an art which can only be acquired with practice and constant application. The following points, which are the result of experience at sea, may be found useful.

a. Basic technique

Suppose that the surveyor wishes to ink in the soundings between fix 1 and fix 2, and that his assistant is ready to operate the trace reader for him. The procedure is as follows:

(1) Fix 1 is placed under the reading scale, the reduced sounding is read off by the assistant and the surveyor inks it in; the figures should be orientated in a north–south direction, with a slight slope to the right if desired. It is easier to make sloping figures look nice.

(2) Fix 2 is placed under the reading scale, and the procedure is repeated.

(3) The surveyor now estimates how many soundings he can fit in between the two figures on the tracing. Suppose there are five. He says to his assistant, 'middle and two either side', and duly receives the intermediate soundings in the order 3, 1, 2, 4, and 5. If four soundings between fixes are required the instruction 'four in order' will produce them in the sequence 1, 2, 3, and 4. It is usually better to demand an odd number, as their spacing on the tracing is then simpler.

This procedure is repeated for all the fixes.

Note that the surveyor does the inking in, whilst his assistant operates the trace reader. This method is the only safe one, since only the surveyor himself can interpret his work properly. He must not, however, allow his primary duty of inking in blind him to his responsibilities concerning the operation of the trace reader. He should examine the whole trace as it comes on to the face of the machine, and before it is inked in, and point out to his assistant any special soundings he wishes to show on his tracing. He may at times have to refer to the trace reader whilst he is inking in, so that he can visualise the hills and valleys which he is trying to depict.

Where the bottom is even, inking in is simple and may proceed at a relatively high speed. Where peaks and deeps abound on the trace, the process should never be hurried. It should always be remembered that a shoal sounding missed during the inking in process may be lost for ever, or until it is rediscovered by the keel of some unsuspecting ship.

It is a good idea to mark shoal soundings or obstructions which will probably need further investigation with a soft pencil as they are inked in. Only too often in the past have surveyors spent valuable minutes searching for a shoal sounding in a maze of figures, which, had it been marked at the time it was inserted, would have been quite apparent. In areas where wrecks are numerous it will be advisable to record their positions and the nearest fix number as they are inked in.

b. Size and spacing of figures

Where more than one surveyor is working on a chart at the same time, it is important that the officer in charge should lay down definite standards concerning the size and spacing of figures, and insist that they are adhered to from the outset. An accurate and pleasing fair chart or final tracing cannot be made from sounding tracings on which the size and spacing of figures vary.

Where the bottom is even, there is no need to crowd soundings obtained by echo sounder closely together. Everyone knows that they are spot depths along a continuous section of the sea bed. If soundings in individual lines are spaced between one-tenth and one-eighth of an inch apart they will be quite close enough. They should be inserted as regularly as the ability of the surveyor will allow, and be of a size that conforms well with their spacing; if there is any doubt, reasonably small (but very legible) figures spaced fairly openly will generally look better than large figures crowded together.

Where the bottom is irregular, or when inking in examinations, it may well be prudent to reduce the size of the figures slightly, and space them more closely. Even so they must still be of a reasonable size, and not too crowded. If it is impossible to read them with the unaided eye, and to read them with certainty, then they are too small, or crowded too closely together, or possibly even both.

If the surveyor carrying out an examination finds that he cannot insert sufficient soundings properly to delineate the sea bed without breaking the rules set out above, then he must increase the scale of his work until he can.

c. Inserting fathom lines after inking in

When all the soundings have been inked in, the fathom lines may be inserted. It is best to do this lightly in pencil to begin with, and not to use ink until it is quite certain that they have been drawn correctly. It is normal to insert the drying line and the 1, 3, 6, 10 and 20 fathom lines in all surveys; in deeper water the surveyor must use his judgement, and insert those fathom lines which will be of most use to the mariner.

d. Inserting fathom lines before inking in

If the fathom lines are drawn after the soundings have been inked in, there will be a possibility, greater or small scales, that they may be slightly displaced from their true positions owing to the size of the figures, or to bad spacing of soundings between fixes. This may not be acceptable, particularly when narrow channels with steep banks are being delineated.

In these circumstances important fathom lines may be taken directly from a trace reader set with the tidal reduction, and sketched in carefully on the board, before the soundings are inked in. The latter are then inserted so that they conform. If it has been arranged in the field that fixes have been obtained on or close to these important fathom lines, so much the better (*see* Section 25d of this chapter).

e. Sounding tracings; overlaps

Sounding tracings may be of any convenient size. Large ones are more difficult to handle and more easily damaged than small ones.

Each tracing should have generous overlaps with its neighbours. Care is necessary to ensure that the inked in soundings agree in the overlapping areas. The officer in overall charge of a survey usually makes it his personal business to attend to this point, deleting or amending soundings as necessary so that they all conform exactly, both in position and depth.

The sounding tracings are the raw material from which the fair chart or final tracing will be made. They must therefore be handled with great care. It is usual to keep them between sheets of paper which have been bound into a looseleaf folder with stiff covers.

33. Measuring Areas; Simpson's Rule

The surveyor is often required to measure areas of irregular shape, when compiling reports. He may use Simpson's rule in most cases. Referring to Fig. 3–50, which shows an irregular figure whose area is required, the procedure is as follows:

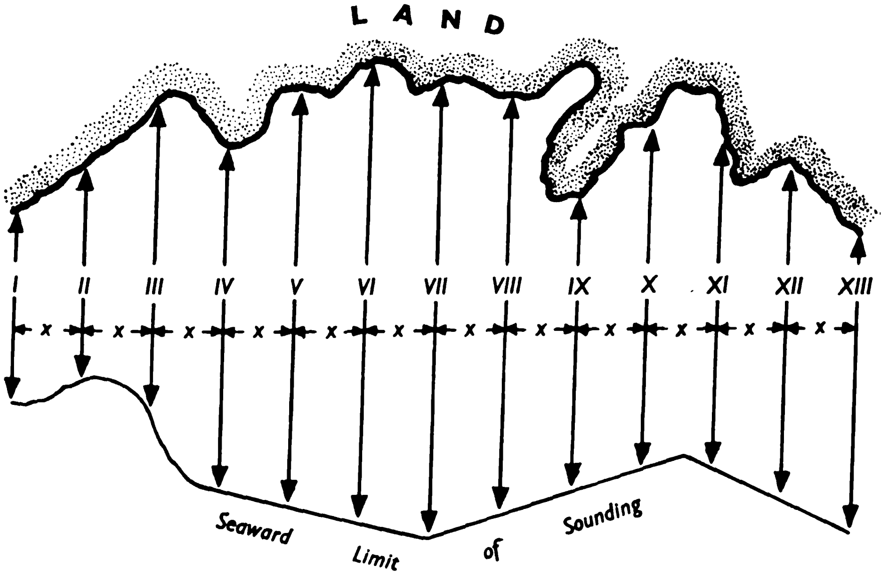

Fig. 3–50

(1) Divide the area into an even number of strips of equal width. The more strips there are the more accurate will be the result. Number the dividing lines, or ordinates; there will be an odd number of them. In the figure there are 12 strips and 13 ordinates.

(2) Measure the length of each ordinate, and the common width of the strips, x.

(3) Then the area of the figure is given by the following formula:

$$\text{Area} = \tfrac{1}{3}\begin{array}{c}\text{common width}\\ \text{of strips}\end{array}\left[\begin{array}{l}\text{Sum of end ordinates} + \text{twice sum of other odd}\\ \text{ordinates} + \text{four times sum of even ordinates}\end{array}\right]$$

Applied to Fig. 3–50, this becomes

$$\text{Area} = \tfrac{1}{3}x\ [I+XIII+2(III+V+VII+IX+XI)+4\,(II+IV+VI+VIII+X+XII)]$$

In the strict application of Simpson's rule each ordinate must cut the bounding lines of the figure in two places only. In the diagram it can be seen that ordinate *IX* really cuts in four places, owing to the configuration of the land. This will introduce errors, but these can be compensated for in most cases by the application of common sense. A more accurate result would be obtained naturally if the width of the strips was reduced to a half, or even a quarter, of that shown.

Part 5 Deep Water Sounding

34. Introduction

The principles that govern the conduct of deep water sounding are the same as those which apply to shallow water work. However, since deep water sounding instruments are generally used under comparatively severe conditions, the surveyor must, when using them, consider factors which he may safely neglect in shallow waters. The movement of the ship (rolling and pitching) can affect the echo trace very considerably. No echo sounder in existence at the present time (1965) can give a complete and accurate picture of the sea bed in deep water, because its beam width will be much too large. The analogy of human vision may be quoted as an example of the sort of thing that happens. A sheet of squared paper held at arm's length is well defined by the average eye. Take it 20 feet away and the individual squares merge into a grey background; the eye is no longer capable of resolving them. In a similar way an echo sounder working in deep water is not capable of resolving quite large features on the sea bed. Until it becomes possible to manufacture a really narrow beam transducer, and to stabilise it so that it always looks vertically downwards regardless of the ship's motion, this inherent drawback will have to be accepted.

In what follows some of the difficulties which are encountered in deep water work will be discussed, together with ways in which their effects can be lessened or overcome.

35. Transducers for Deep Water Work

In theory the ideal transducer for deep water work would have a very narrow beam, its mounting would ensure that it always directed its energy vertically downwards, and it would not be affected at all by the ship's motion in rough weather.

Narrow beams can be produced by raising the frequency very considerably, by making the transducer reflector very large, or by using a multiple and complex transducer array. None of these solutions is very attractive, and most modern deep water sets have a relatively wide beam, and generate a fairly high powered signal with a simple transducer of moderate proportions.

The transducers of a narrow beam echo sounder would have to be stabilised in roll and pitch, to work efficiently. Imagine a set with a total beam width of 10°, fitted in a ship which is rolling 10° or so. Suppose that the vessel is on an even keel as a transmission is made, in a depth of about 1,000 fathoms. The transmitted energy will strike a level sea bed at right angles, and be reflected vertically upwards; but when it arrives back just over two seconds later the ship's transducer may well be more than 5° (half the beam width) out of the vertical, due to the ship's motion, and will not respond to the signal. Again, all signals transmitted in directions more than 5° out of the vertical will have very little chance of being detected on their return from the bottom.

Stabilisation adds to the complexity and cost of the equipment. At the present time it is only used in very special circumstances. Most deep water sets have a total beam width of 30° to 40°, which allows a vessel to roll and pitch moderately before signals are lost from this cause.

When a moving ship pitches aerated water is carried under her bottom, and across the path of the echo sounder's transmissions if the transducers are fitted near the bows. Quite a thin layer of aerated water will completely absorb and scatter all sound energy, an effect which is known as quenching. Quenching is reduced if the transducers are placed fairly far aft in a ship; it can be avoided entirely either by placing them in a 'fish' towed close alongside, but clear of the interference caused by the ship's hull, or by mounting them in a pod supported on a shaft well below the ship's bottom.

36. Recorders for Deep Water Work: the Precision Depth Recorder

Any recorder which has a suitable depth scale may be used for deep water work. It will, however, not be of very much use to the surveyor unless the speed of the motor which drives the stylus can be relied upon to remain constant over fairly long periods of time. Many governing mechanisms are not sensitive enough or reliable enough for deep water work. A good governor should maintain a set speed over a period of several hours, with a variation not greater than one part in two or three thousand.

The speed of rotation of the stylus should be checked at least once an hour whilst a deep water set is in use. If the results are noted the observed depths may be corrected to conform to any specially selected equivalent sounding velocity, by the methods described in Section **4b** of this chapter.

Under difficult conditions, when the returning echos are very weak and perhaps masked on the trace by noise, it will quite often be a good plan to place a pair of headphones across the stylus input terminals, and listen. Experience has shown that a weak signal is often strong enough to be heard quite well in headphones, but not strong enough to mark dry recording paper. When searching for a weak bottom signal in an unknown depth, the use of headphones can be a great help, since they are not affected at all by the phase setting of the recorder, and the human ear can identify the echo by its quality as well as its intensity. On one occasion in the Leyte Deep the bottom was positively identified in just under 5,000 fathoms in very adverse weather conditions by initiating a succession of transmissions by hand, and listening for the returning echoes; the echo trace was blackened completely by noise long before the amplified echo itself was powerful enough to mark it.

a. The precision depth recorder*

Precision depth recorders have been developed by oceanographic specialists who wished to record comparatively small undulations in the sea bed in great depths. They may be used with almost any combination of transmitter, transducer, and receiver which is itself suitable for deep water work. They have been adopted by the surveyor, since they more than meet his requirements.

A precision depth recorder has one main difference from the type of recorder normally used by the surveyor. Its depth indicating device is driven by a synchronous motor, whose speed is locked electrically to a frequency generated by a tuning fork or crystal. The stylus speed, and hence the equivalent sounding velocity of the machine, is very stable indeed over comparatively long periods; it is not likely to vary by more than one part in 10,000.

Most precision depth recorders are designed so that their equivalent sounding velocities are fixed at either 800 or 820 fms/sec.; it is not possible to vary the motor speed easily in the field, but it is a simple matter to check it by injecting one of the standard frequencies which are broadcast continuously by stations such as WWV. A straight line trace makes phasing automatic; special devices make the detection of an echo 'once round the clock' comparatively simple. Operating instructions are supplied with each unit.

It is important to realise that, despite the name which has been attached to it, a precision depth recorder is quite incapable of measuring depth, with or without precision. It measures the time taken by an echo pulse to proceed to and return from the sea bed with great precision, and automatically converts this time interval into 'depth' on the assumption that the echo pulse was travelling at a certain speed (generally 800 or 820 fms/sec.). Experience has shown that ships fitted with precision depth recorders can return to the same spot in the deep oceans several times over a period of years, and each time obtain the same apparent depth to within a fathom or so, in 2,000 or 3,000 fathoms. This indicates two things:

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* The instrument's name is misleading, since it does not record depth precisely, but time only.

(1) That the recorders themselves are well worth having, since they have great stability over a period time, and

(2) That the average velocity of sound in a column of water in the deep oceans changes very little over a fairly long period of time.

It does not mean that the depths indicated by the recorder are correct, since it is not likely that the average velocity of sound in the column of water concerned will coincide with the equivalent sounding velocity of the machine.

37. Natural Phenomena which affect Deep Water Sounding

It has been seen that the width of the echo beam and the movement of the ship affect deep water work. Various natural phenomena also have an effect.

a. The deep scattering layer

The deep scattering layer (*see* Section 5c of this chapter) can at times cause quite a firm echo on the trace, which may lead the unwary into assuming that it is the return from the sea bed. The true bottom echo will nearly always be obtained through the scattering layer, but it may well have to be searched for with the phasing controls. If there is doubt a pair of headphones applied across the stylus input terminals will generally resolve it. As a last resort a leadline or wire sounding may be needed positively to identify an echo from the deep scattering layer as being false. Echoes from the layer may be seen in the top left hand corner of Fig. 3–52(a); they are not, as they appear to be, at 1,720 fathoms, but at 120 fathoms; the bottom echoes in this figure are 'twice round the clock'.

b. The quality of the bottom; hyperbolic echoes

If the bottom is level and smooth it may act like a flat mirror, and reflect back to the ship only that part of the echo beam which strikes it at right angles. Provided it is not penetrated, it will produce a thin firm trace of about the same width as the transmission pulse. If the sound energy does penetrate into the sea bed for any distance, additional echoes may be received off the underlying layers; the trace will then be thicker than the width of the transmission pulse, and it may well be possible to see the various layers; this is most likely to occur when mud or silt lies over rock or sand.

Many apparently smooth and level bottoms do not act like mirrors, for the various particles forming them are comparatively rough, and each particle reflects back any part of the echo beam which strikes it at right angles. The first return will come from that part of the bottom directly below the ship; later returns will come from the outer parts of the area 'illuminated' by the echo beam, and the trace will be much thicker than the width of the transmission pulse; it will generally be dark and solid, and not show any echoes from layers below the sea bed.

If the bottom is sloping, the first return will not come from a point directly below the ship, but from that part of the bottom which lies the shortest distance from the vessel's transducer; the apparent depth at a point will then always be slightly less than it should be. If the slope of the bottom is more than half the angular beam width of the echo sounder, and the reflection is perfectly mirror like, then in theory none of the reflected energy will reach the ship, and there will be no bottom trace at all. In practice echoes can be obtained off slopes much steeper than half the beam width, since no material on the sea bed reflects as a perfectly flat mirror; experience has shown that the best trace will be obtained off a steep slope if the vessel is proceeding from deep to shallow water at right angles to the fathom lines.

(i) Hyperbolic echoes.* If the bottom is undulating, or rugged, almost anything may happen, and hyperbolic echoes are very likely to appear on the trace.

In Fig. 3–51 the ship is proceeding from left to right across the paper, in a depth of just under 1,400 fathoms; the sea bed is drawn to scale below her. Imagine that she is fitted with a very special echo sounder, whose beam width is 40° in a fore and aft direction, but 0° in the athwartships direction; this will make the explanation which follows simpler, since everything will take place on the plane of the paper.

For some time before reaching position (a) the ship has been proceeding over a comparatively flat and smooth bottom; the echo trace (extreme left) is firm, and about

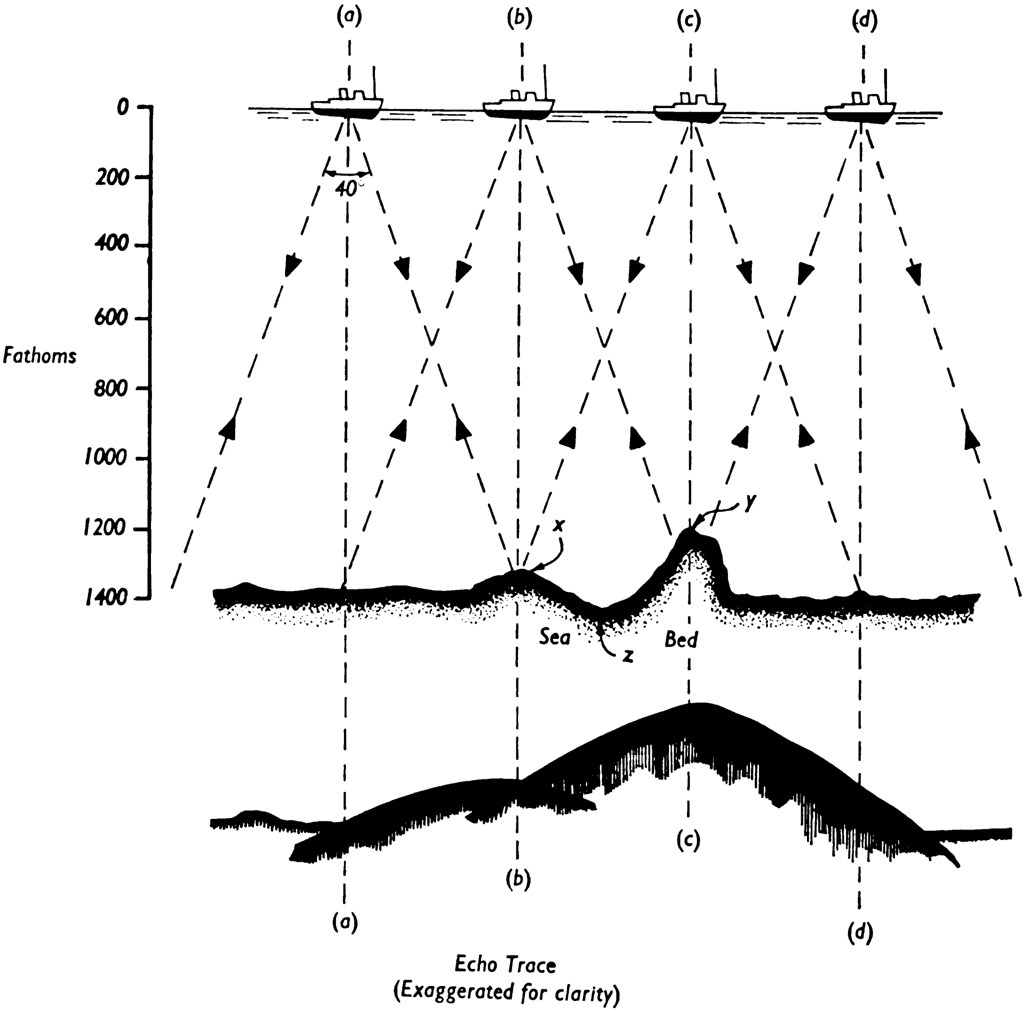

Fig. 3–51

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[*] Hyperbolic echoes are true hyperbolae only in theory. In practice their shape may be almost any smooth curve.

the same width as the transmission line. Just before (a) the leading edge of the beam strikes the slope of the shoal *x*, and an echo is obtained from it as well as from the bottom vertically below the ship; since the slant distance to the shoal is greater than the depth, this echo will appear below the sea bed. At (a) the slant distance to the shoal *x* and the vertical distance to the bottom are equal; the hyperbolic echo from the shoal therefore passes through the bottom echo at this point. Between (a) and (b) the true bottom echo is continuously masked by the spurious hyperbolic echo from *x*, since the slant distance to the shoal is at all times less than the vertical depth. If *x* were an isolated feature, its hyperbolic echo would rise to a crest at position (b), which is the only point on the hyperbola where true depth and apparent depth coincides, and then fall away once more. But unfortunately shoal *y* is detected by the leading edge of the echo beam just before the ship reaches (b). Its hyperbolic echo rises from a point below that caused by *x*, passes through it at (b), where the vertical distance to *x* and the slant distance to *y* coincide, and then takes over completely. The least hyperbolic depth at (c) is equal to the true depth, since the ship is then vertically over the shoal. The true bottom is not picked up again until the distance to it becomes less than the slant distance to *y*; this does not occur until the ship is well past (d).

Note how the echo has failed completely to detect the valley *z*, which lies between the two shoals. Note too how the width of the trace varies from place to place, indicating that the reflective qualities of the bottom are variable.

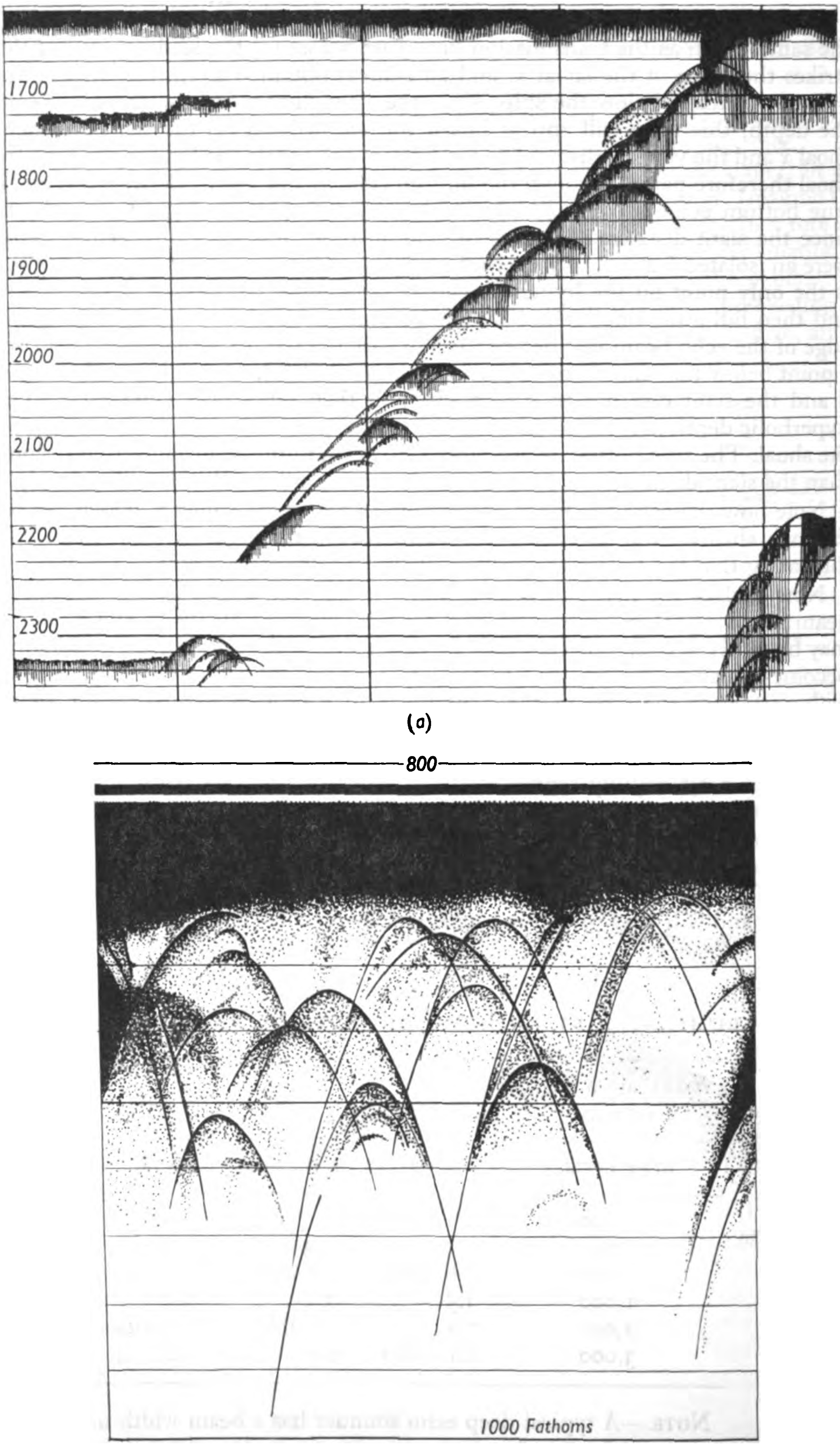
Now replace the fictitious echo sounder considered above with a real one, whose beam is a cone of 40° apex angle, and consider what may happen. Hyperbolic echoes may be received from objects which lie either side of the ship's path, and the position becomes much more complex. It will, in fact, be impossible to interpret the echo trace with certainty; the tops of the hyperbolae may or may not be true least depths, depending on whether the objects they come from lie in the ships path or to one side. The surveyor can in these circumstances be certain of one thing only; that the echo trace does not faithfully represent the bottom; this follows naturally from the fact that the resolution of a beam as wide as 40° is very low.

The table below shows the diameter of the circle on the bottom 'illuminated' by echo beams of varying width. Features whose horizontal dimensions are less than the diameter of this circle will have very little chance of being resolved by the echo sounder, and will very probably cause hyperbolic echoes.

THE DIAMETER OF THE CIRCLE ILLUMINATED BY AN ECHO SOUNDER IN VARIOUS DEPTHS

TOTAL BEAM WIDTH OF ECHO	20°	30°	40°
DEPTH (FMS)	DIAMETER OF ILLUMINATED CIRCLE		
20	42 ft	64 ft	87 ft
100	212 ,,	322 ,,	437 ,,
500	1·8 cables	2·7 cables	3·6 cables
1,000	3.5 ,,	5.4 ,,	7.3 ,,
2,000	7.1 ,,	1.1 miles	1.5 miles
3,000	1.1 miles	1.6 ,,	2.2 ,,

NOTE.—A typical deep echo sounder has a beam width of about 40°.



(a)

(b)

Fig. 3-52

(ii) Interpreting hyperbolic echoes. The following procedure is recommended:

(*a*) Mark the crests of the individual hyperbolae on the trace.

(*b*) Join these crests with a smooth curve, and assume that this represents the bottom.

To attempt anything more rigorous than this is analogous to trying to take measurements to the nearest thousandth of an inch from a television screen with only 50 or 100 lines to the inch; there is very little point in searching for detail which cannot be resolved by the equipment being used.

Fig. 3–52 shows two examples of hyperbolic traces. The first (a) is relatively simple, and probably bears a reasonable resemblance to the actual sea bed. In (b) the record is so complex that no prudent surveyor could obtain more than an indication of the general depth from it.

38. Adjusting Deep Soundings

Unless a precision depth recorder is being used, the equivalent sounding velocity of the machine will probably vary slightly with time. Periodic checks of the stylus speed will enable it to be deduced from Fig. 3–19.

Before inking in deep soundings the surveyor should always adjust them to conform with a fixed equivalent sounding velocity, generally either 800 or 820 fms/sec. by the method set out in Section 4b of this chapter. If the apparent depths have been booked at the time they were obtained, it will be a good plan to enter soundings adjusted to the selected equivalent sounding velocity above the originals in the deck book; for preference a different coloured pencil should be used. If the work is inked in directly from the trace, the adjustment may conveniently be carried out on a hand calculating machine as the works proceeds.

Whichever method he adopts the surveyor must ensure that a permanent record of the actual time intervals measured by the echo sounder is available for future reference. If all the depths on his sounding tracing are adjusted to the same equivalent sounding velocity, and this velocity is quoted, this requirement will be fulfilled. An equally good record would be a deck book filled in as described above.

a. Apparent depth and true depth; the use of tables giving the velocity of sound in water

Apparent depth can be read off an echo sounder. It will be meaningless unless an equivalent sounding velocity is quoted, and will then become merely a convenient way of expressing a time interval.

Knowing the equivalent sounding velocity, apparent depth may be converted into true depth if the actual average velocity of sound in the column of water concerned is measured. At the present time (1965) true depth in the deep oceans can be obtained by no other means available to the surveyor. A wire sounding cannot be relied upon to give it, since it is most unlikely that the wire will remain vertical, or even have a constant inclination to the vertical, throughout its length.

Various tables are in existance at the present time (*Tables for the Velocity of Sound in Seawater*, H.D. 282, is an example) which tabulate average sounding velocities for various areas of the world and various depths. They also usually tabulate corrections which may be applied to soundings obtained with equivalent sounding velocities of 800 or 820 fms/sec. to reduce them to what the tables describe as 'true depths'.* These tables will be improved upon as knowledge of the deep oceans increases. A surveyor using them should take great care as he crosses the various area boundaries, or he may find himself showing a non-existent cliff face on the boundary line, where the correction may jump suddenly by several fathoms.

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* The first tables were compiled in the early 1930s, when deep sea echo sounding was in its infancy, and almost all charted depths in the deep oceans were the result of wire soundings. They were intended to enable the surveyor to adjust his new-fangled echo soundings to make them conform with 'true' soundings obtained by wire. At the present time (1965) they are used by some charting authorities, and rejected by others.

For general work the use of these tables is not recommended, since it will introduce an additional (and possibly spurious) correction, and tend to make the all important originally observed time interval much more difficult to find if it is required in the future. If the tables are used then the surveyor must record in his deck book the apparent depths obtained at a certain equivalent sounding velocity, and the corrections applied to these depths to convert them to 'true depths'.

A surveyor wishing to compare his own deep soundings with those shown on a published chart must always find out to what equivalent sounding velocity the latter have been referred, and whether or not additional adjustments obtained from tables such as those referred to above have been applied to them.

39. Fixing Whilst Sounding in Deep Water

The track of a vessel sounding in deep water will generally be controlled by astronomical observations or long range electronic devices. In both cases the technique of fixing follows normal navigational practice, but the surveyor will of course obtain as many position lines as he can at each fix, and take particular care to eliminate as many errors as possible from his observations.

If possible, the position lines forming a fix should be inked in on the sounding tracing or plotting sheet, in a colour different from that used to show the soundings. In the report which accompanies a tracing or plotting sheet showing deep soundings, the surveyor's estimate of the standard errors of his fixes should always be included; a line of soundings controlled by poor fixes* may be of great use, provided the quality of the fixes is known; the same line forwarded into office with no estimate of the errors of fixing can do a great deal of harm and cause much unnecessary work.

40. Plotting Deep Soundings; Oceanic Plotting Sheets

Oceanic plotting sheets are published in two series, on scales of 1/1,000,000 and 1/250,000, by the Hydrographic Department. They cover the whole world. When a ship is obtaining deep soundings, and fixing herself astronomically, she should if possible use these plotting sheets. If visual bearings or electronic fixes are being obtained the largest scale published chart should generally be used.

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* These poor fixes must not of course be attributable to any deficiency on the part of the surveyor.

Part 6 Searching for Reported Shoals

41. Introduction

Searches for reported shoals and dangers must often be carried out by a surveying vessel, and may occupy a considerable time.

Experience has shown that many reports are based on erroneous observations or deductions.

For example:

(1) The lead has not struck bottom when it appears or was supposed to have done so.

(2) Discoloured water has been assumed to indicate the presence of a shoal, whereas it was actually caused by a concentration of small organic or inorganic matter, such as plankton.

(3) A line of soundings obtained by echo sounder has been one or more times 'round the clock'. This type of report is probably most common today, emanating as it does from ships fitted with powerful echo sounders.
The shoal may be real enough, but reported in the wrong place, due to bad fixing or for other reasons.*

When he is ordered to search for a reported shoal, the surveyor should always endeavour to obtain a copy of the original report, as without it he will be unable to conduct his search properly. A study of this report will very often enable him to assess the likelihood of the shoal really existing. Well over half the reports received are proved to be false on investigation; this fact should not, however, deter the surveyor from making as thorough a search as the circumstances warrant.

In the sections which follow various factors which should be borne in mind are discussed.

42. Assessing the Report; Planning the Search

There are three basic types of report: those based on leadline sounding, those based on soundings obtained by echo, and those based on visual observations.

a. Report based on a single leadline sounding

A reported shoal based on a single leadline sounding is one of the least likely to exist, and at the same time one of the most difficult to disprove. If it is true it means that the depth reported exists over an area about the diameter of a small cup; it may be the top of a pinnacle rock, or lie anywhere on a larger formation whose least depth may be less than that reported.

The surveyor should ask the following questions before he carries out his search:

(1) Why does the report consists of one sounding only?

(2) Was a sample of the bottom brought up on the lead? If so, what was done with it?

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* In one instance a vessel struck a charted reef in the Pacific Ocean and was damaged. There were no witnesses. The master reported that he had struck a new shoal in uncharted waters about 20 miles away, where the bottom was later found by a surveying vessel to be quite flat and nearly two miles deep. The vessel's owners received full compensation for the damage from an insurance company.

(3) Why did the reporting ship not verify her reported sounding by running a line of soundings?

(4) By what means was the reported sounding fixed?

It may unfortunately happen that these questions cannot be put, although they would probably reduce the author of the report to confusion. In that case the report must be taken at its face value, and the consequent probable waste of time accepted.

When planning his search, the surveyor should bear the following points in mind:

(1) The reported danger may be the summit of a small feature which rises abruptly from the sea bed. In shallow waters it may perhaps be a pinnacle rock.

(2) On the other hand it may be an indication of even shoaler water, which may be a danger to the investigating vessel.

(3) The reported position of the shoal may not be correct. A position based on compass bearings or electronic devices may have equal errors in any direction; one based on astronomical observations is likely to have greater errors of longitude than of latitude.

b. Report based on a line of leadline soundings

A report based on a line of leadline soundings is much more likely to be genuine. However, the possibility still remains that the reported position of the shoal may be in error, due to bad fixing.

The surveyor faced with such a report should ask any of the questions in a above that may be relevant, and plan his search on similar lines. It may well be possible to measure the reliability of such a report by the method outlined in d below.

c. Reports based on a single sounding obtained by echo sounder. No trace available

A report of a single shoal sounding obtained by echo sounder should be dealt with in the same way as the single leadline sounding referred to in a above. No competent mariner should ever make such a report, as it is very nearly useless, and may well cause a surveying ship to waste a great deal of time.

d. Report based on a line of soundings backed up with the original echo trace

In this case the surveyor should obtain the echo trace, and the record of the reporting vessel's course and speed whilst it was being obtained. He should plot soundings from the trace on the largest scale published chart of the area, marking the shoalest sounding obtained.

The veracity of the report may then be tested very simply by running one line of soundings through the reported position of the shoal, and at right angles to the reporting vessel's course.

In Fig. 3–53 the track of the reporting ship is represented by *AB*; from her records a 10-mile-long section from the water surface to the sea bed has been constructed; it is shown shaded. Reported depths along this track vary from 150 fathoms, to 20 fathoms at the shoalest point *x*. The echo trace accompanying the report is good, and there is no doubt that the record is of the bottom.

The surveyor runs one line of soundings *CD*, 10 miles in length, at right angles to *AB* and passing through the point *x*. He constructs a section from the water surface to the sea bed along his track (it is shown unshaded) and fits it to the reporting ship's section as shown in the diagram. At no point in his line of soundings is the depth less than 600 fathoms, and at *x* it is 620 fathoms.

Now, if the surveyor's work is to be relied upon, then either the position of the reported line of soundings is in error by at least five miles (the error very probably is much more than five miles—compare a maximum of 150 fathoms reported with a

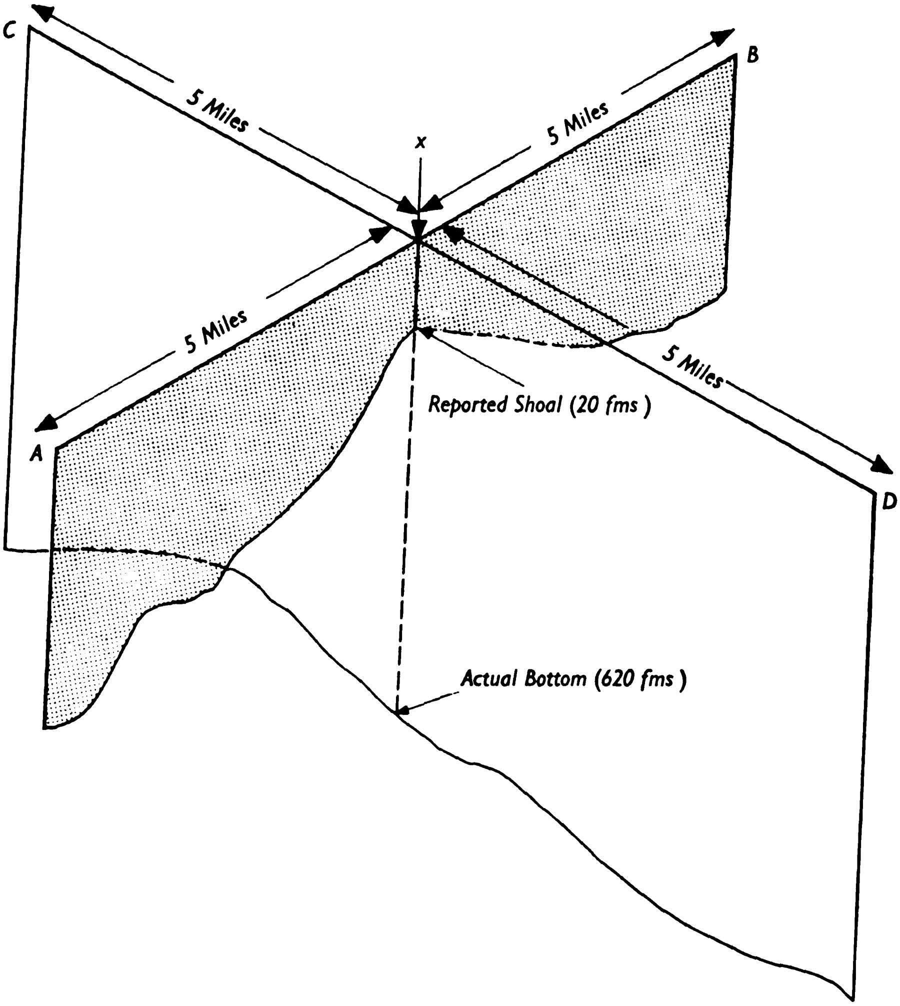


Fig. 3-53

minimum of 600 fathoms obtained), or the reported soundings themselves are in error. In this case it is quite likely that all the reported soundings are 'once round the clock'.

In practice there is no need to make the templates shown in the figure. The whole picture can be visualised in the surveyor's mind. The lines *AB* and *CD* should of course be as long as possible, and equal if possible.

Note that the echo trace from the reporting vessel must be considered as a whole. No sounding on it can be treated as though it had been obtained in isolation. This makes the surveyor's task much easier.

In the example quoted the reporting ship must either have very seriously misread her echo sounder, or misplotted herself by at least five miles. This will generally throw sufficient doubt on the veracity of the report to enable it to be discounted; the surveyor would be justified in not devoting any more time to the investigation unless additional evidence indicating shoal water was presented to him.

It will sometimes happen that the depths on the test line of soundings, although not agreeing anywhere with the reported depths, are near enough in places for the explanation to lie in small errors in the reporting ship's positions or recorded depths. In this case the surveyor would be wise not to reject the report too hastily. He may run additional lines parallel to his first one, and on either side of it; each one that confirms his own work and disagrees with the report will strengthen the evidence against it. The longer these lines are the better.

In the extreme case where the original report is true the new work will agree with the old wherever the lines cross, and the surveyor will build up a detailed picture of the sea bed in the normal way.

e. Visual reports of shoals or discoloured water

Sometimes a ship reports that 'the bottom was suddenly sighted', or that 'discoloured water was observed in a certain position'.

Mariners who 'suddenly sight the bottom' when they do not expect to do so should be asked why a positive sounding of some sort was not obtained, preferably with a sample of the sea bed. Their reports are likely to waste much time, particularly if the investigating surveyor is unable to get more than a second hand account of their experience. Unfortunately some of these reports turn out to be true.

Reports of discoloured water generally refer to a discolouring substance actually in the surface layers, having nothing whatever to do with a shoal. Again, the originator of such a report should be asked why a sounding was not obtained, if shoal water was suspected.

If an investigation into these types of report is carried out, it should be conducted on the lines quoted in a above.

43. Types of Search

a. The star search

The star search is illustrated in Fig. 3–54(a). A beacon, or other reference mark, is laid on top of, or in the reported position of the shoal, and the ship then stars round it.

The star search has been used for very many years. It is ideal when the only way to fix is to run a compass-log traverse, but the continual returns to the beacon mean that the central part of the area is covered too thoroughly, whilst the outer parts may be insufficiently examined. It is therefore not a very efficient way to carry out a search.

If the beacon is laid on top of a shoal, the starred lines will probably cut the fathom lines at a broad angle; this advantage is not held to such an extent by the spiral box and rectangular searches referred to below.

If radar is available the starred search should not be used, unless there are special reasons which make it attractive.

b. The spiral box search

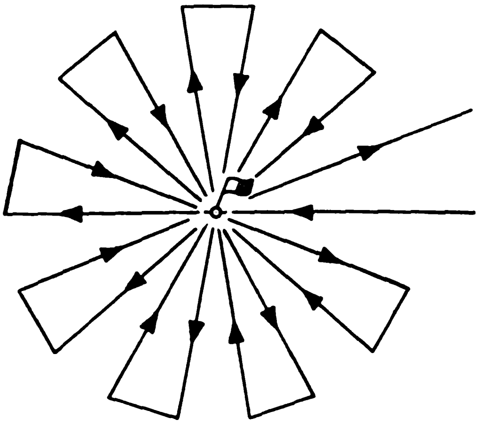
A spiral box search covers the ground quickly and evenly, though it is not so easy to modify as the search proceeds as a rectangular search. It may be controlled by any convenient means; in Fig. 3–54(b) the control might well be provided by gyro bearings and radar ranges of the beacon. It may not delineate the fathom lines on a shoal very well, as it is quite likely that some of the lines of soundings will be run parallel to them.

The spiral box search should generally be used in preference to the star search by any vessel fitted with an accurate electronic ranging device. It can also be most useful when Oropesa or sonar sweeping is being carried out; in the figure a vessel sweeping to starboard could herself always remain in swept water.

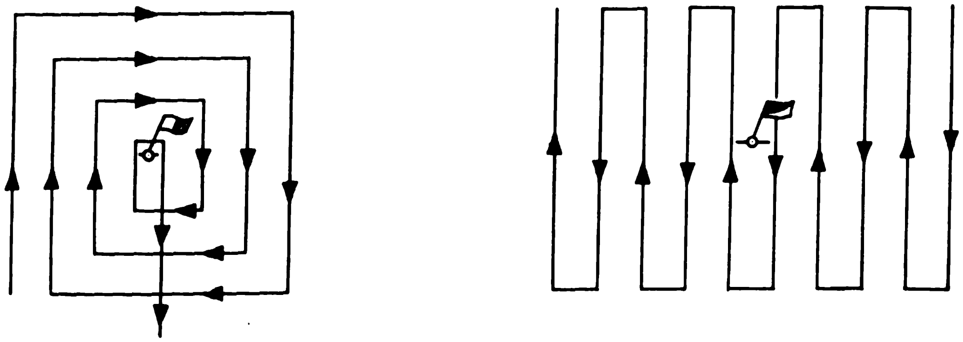
It would of course be equally correct to start the search at the beacon, and work outwards.

c. The rectangular search

The rectangular search, illustrated in Fig. 3–54(c), follows normal sounding practice. It may be made round a single beacon provided good gyro bearings and ranges can be



(*a*) *Star Search*



(*b*) *Spiral Box Search*

(*c*) *Rectangular Search*

Fig. 3-54

obtained. It lends itself more easily to changes of plan in the field than the spiral box search, and the surveyor is not so likely to find himself running along the fathom lines, provided he has chosen the direction of the sounding lines well.

44. Searching for Shoals; Distance apart of Lines of Sounding

Where the general depths are less than 100 fathoms, dangers may sometimes exist which rise almost vertically from the sea bed. Slopes of 60° from the horizontal have been found in general depths of just under 1,000 fathoms.

Thus a dangerous shoal could exist about two cables from a sounding of 500 fathoms, or five cables from a sounding of 1,000 fathoms. Below 1,500 fathoms the slope of the sea bed is not very likely to exceed 15° from the horizontal.

Fig. 3-55 has been constructed on the assumptions quoted above. It shows the sea bed rising from depths of over 3,000 fathoms to a coral islet, and a ship sounding just under six miles from the latter. Although the echo beam covers a large area of the bottom, too much

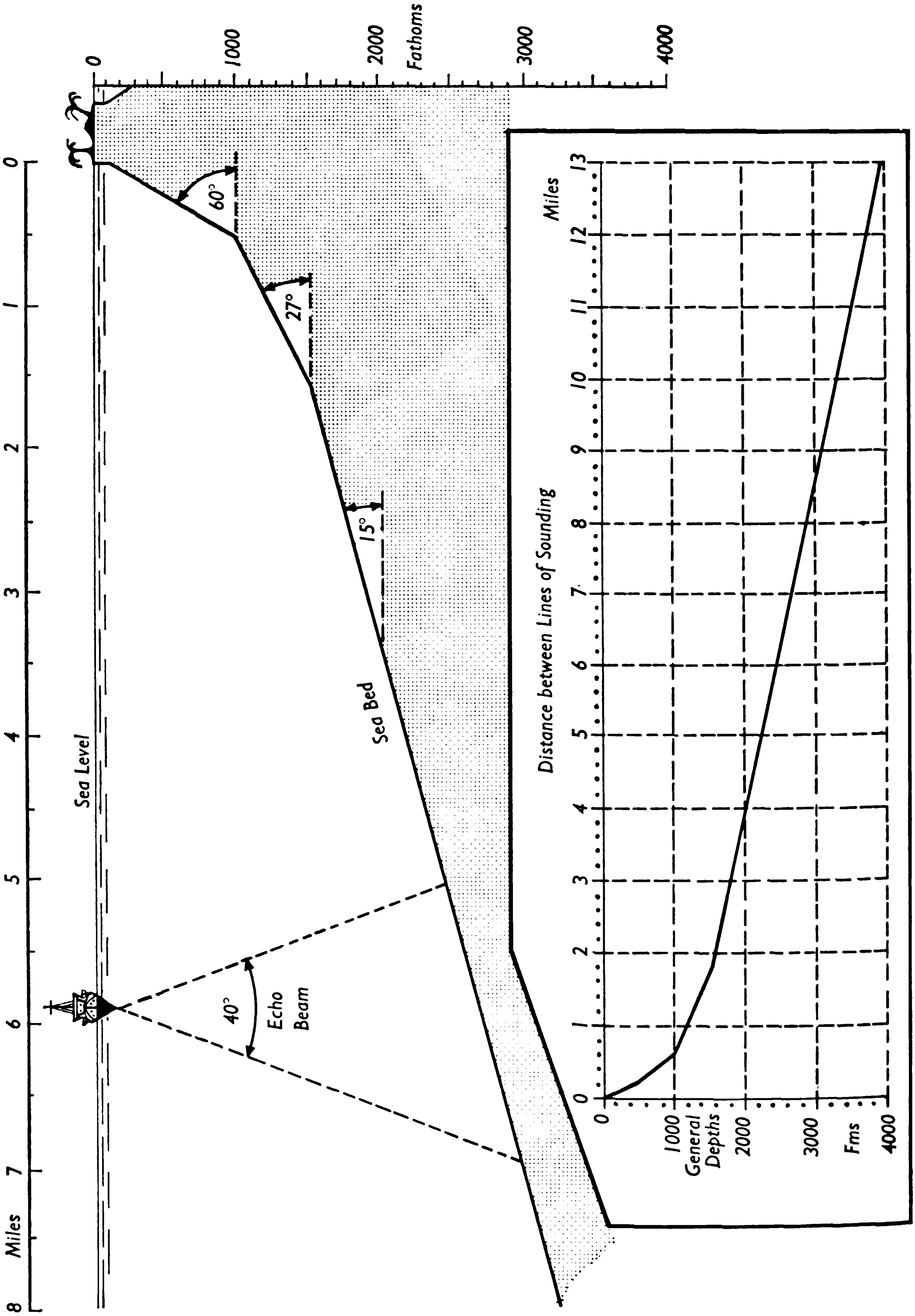

Miles
2000
Fathoms
Sea Level
Sea Bed
60°
27°
15°
40°
Echo
Beam
Distance between Lines of Sounding
Miles
General
Depths
2000
Fms

Fig. 3–55

reliance should not be placed on this fact when deciding upon the distance apart of the lines of sounding.

The inset to the figure may be used as a guide when deciding how far apart the lines should be. It has been constructed mainly from the results of practical experience with echo sounding equipment; it assumes that the surveyor is working in a thick fog or at night, with no detection devices other than his echo sounder. Only in the most exceptional case should it be necessary to run lines closer together than the curve indicates.

If, for any reason, the surveyor decides to run his lines further apart than the curve indicates, then he should bear in mind that the echo sounder by itself may not give adequate indication of a shoal lying midway between two lines; an intelligent visual search may well partly or completely compensate for this fact. In no case should the surveyor run his lines at spacings more than 160% of those indicated, e.g., 6·4 miles apart in general depths of 2,000 fathoms. It should always be remembered that it is better to examine a small area thoroughly than a large one superficially.

45. Conducting Searches in Shallow Water (less than 1,000 fathoms)

When the general depths are less than 1,000 fathoms, lines of soundings will usually have to be spaced less than six cables apart, if a reported shoal is to have a good chance of being detected with an echo sounder. For this reason the surveyor must be able to fix himself with certainty. It may well be that sonar sweeping will be better than sounding. Cross lines should be run, if the shoal is not discovered and the fixing is not as strong as it might be; if they agree with the main lines the surveyor may have greater confidence in the thoroughness of his search. If sonar apparatus is not fitted it may at times be necessary to carry out a clearing sweep with Oropesa equipment. In this case, good fixing or the use of a dan laying vessel would be essential. When using an Oropesa sweep for this purpose, it will usually be best to carry out a spiral box search, using one leg of the sweep only; the ship will then always remain in swept water. Experience indicates that attempts to run a double sweep usually add to the difficulties of handling the ship, without adding a worthwhile amount to the width of the sweep; double sweeping also requires the ship to steam continuously through unswept water.

When searching for a reported shoal in depths of less than 500 fathoms, the surveyor should never forget that it may at any moment lie right ahead, at a distance of less than two cables. He must make as certain as he can that he will not discover it the hard way—with the keel of his own ship. A boat may be stationed ahead, to report back soundings by radio; sonar may be used to sweep ahead and on either bow; a man may be stationed aloft, preferably wearing polaroid glasses. If a helicopter or aircraft is available, and the water is reasonably clear, a visual search from it will often reveal the presence of a shoal quicker than anything else. Although most coral heads show up clearly from the air, some have a fairly dark purplish hue, which may escape detection; the method is therefore not infallible.

From a height of eye of about 35 feet, and provided that the sun is reasonably high in the sky and behind him, a man wearing polaroid glasses should be able to detect most coral shoals with less than 18 feet of water over them at a range of at least half a mile, by the pale green or brown tinge in the water. Again, this method is not infallible; sometimes dark coloured coral heads with only six feet of water over them can be quite invisible at ranges of about two cables.

46. Conducting Searches in Deep Water (more than 1,000 fathoms)

The prudent surveyor, searching for a shoal in general depths greater than 1,000 fathoms, will make the 1,000-fathom line his danger line. It should be remembered that on a great many coral shoals the living coral forms a ring around the circumference, and the least depths are likely to be found somewhere on this ring, close to deep water.

If the surveyor searching for a shoal in deep water can obtain accurate visual, or electronic fixes, so much the better. Very often the work will have to be controlled by astronomical observations; in these circumstances cross lines should be run if possible, as they will add to the reliability of the work if they agree with the main lines.

An ocean swell may become steeper, or even break, in depths of less than 15 fathoms. Sea birds sometimes congregate over a shoal, feeding on the fish which inhabit the area. Where the tidal streams are of some strength the edges of a bank are often marked by tide-rips; however, the presence of a rip is by no means a certain indication that dangerously shoal water exists; in one case in the Solomon Islands a very unpleasant looking rip merely marked the line along which the sea bed rose sharply from over 300 to just under 100 fathoms. On occasions small fish, being hunted by larger ones, can make the water boil over a small area; the unwary may mistake this commotion for genuine breakers on a shoal. It can usually be correctly interpreted by watching it for some time; if caused by fish it will generally be moving through the water. On one occasion the illusion of breakers was created by abnormal light conditions.

47. Searches with Aircraft; the Use of Aerial Photographs

The following report of a search for coral shoals, carried out in deep water by three ships and two aircraft, will indicate the type of operation in which aircraft may be useful.

Three ships, asssisted by two aircraft working from a shore base, were employed. The ships hove to near beacons, in line and 30 miles apart, fixing themselves astronomically. The aircraft started their run about 15 miles from the end ship and, navigating independently, flew parallel courses about five miles on either side of the centre line of the ships. About 15 miles beyond the third ship each aircraft turned outwards for 10 miles and returned on a parallel course. Thus, between them they flew four lines 90 miles long and 10 miles apart. During the flight they fixed themselves relative to the ships, which made smoke for easier identification; the ships also fixed the aircraft independently. All shoals or suspicious discolourations in the water were fixed from the air, and subsequently investigated by the ships.

A single helicopter could be used in a similar fashion, being fixed from the ship by radar as she made her search.

In good conditions, with clear water, a reasonably high sun, and not too much cloud, coral shoals with less than 18 feet of water over them should show up at distances of at least five miles from an aircraft flying at about 3,000 feet. It might be possible to detect shoals with five or six fathoms of water over them by the paler colour of the water. This method, although it will probably detect nine shoals out of ten, is not completely reliable. Cloud shadows can hide a shoal at the vital moment; some coral heads are dark in colour, and do not show up at all. In one case an aircraft flew right over a dark coral head which had only 10 feet of water over it, and saw nothing, although reefs with 18 feet of water over them were quite clearly seen half a mile away.

Black and white photographs taken vertically from the air will usually show most of the dangerous coral shoals in an area. But they cannot be relied upon completely, especially if there are cloud shadows about or if the sun is reflecting off the water. Coloured photographs are easier to interpret, but again they should never be relied upon implicitly.

Part 7 Bottom Sampling in Coastal Waters

48. Introduction

In places where it is possible for a ship to anchor the mariner needs to know the nature of the bottom, and whether the holding ground is good or not. This information is given to him in the form of nature of the bottom symbols on published charts, with perhaps additional remarks in the relevant volume of the sailing directions. The surveyor must obtain it in the first place. He may do this with an armed lead, a special sampler which may be used underway, by dredging, with a grab or corer, or with the anchor of a beacon or his own vessel. Ideally the nature of the sea bed to a depth of two feet or so should be obtained, so that the mariner will know what the flukes of his anchor will be biting into.

Where it is not possible to anchor the mariner may still like to know the nature of the surface layer of the sea bed, as it may be a useful fixing aid. The bottom fisherman will be even more interested, since his trawling operations must be confined to areas where the nature of the sea bed will not damage his equipment.

When obtaining bottom samples the surveyor must use his judgement, to ensure that he collects enough information without spending too much time over it. In most coastal and harbour surveys it will be sufficient if small samples are obtained with the lead or underway sampling device about one inch apart in all directions on the scale of the survey; these should be backed up with larger samples taken by dredge, grab or corer in places of special interest. No anchor, whether belonging to the ship, one of her boats or a beacon, should ever be weighed without taking a sample from it, if it brings one up.

In some circumstances the best way of determining the nature of the bottom may well be to send down a diver.

49. Sampling with an Armed Lead

The armed lead has been used for bottom sampling for very many years, and is still used from boats to obtain samples. It may be attached to a leadline, or to the wire from a Lucas sounding machine.

Whilst the lead will generally produce something to look at when the bottom is muddy or sandy, it cannot detect the difference between quite small stones and solid rock. Both of these may well dent the tallow, or score the lead itself, and the surveyor working in an area of hard bottom must resist the temptation to use his imagination too much.

Great care must be taken to ensure that the arming material in the lead is quite clean, before the latter is sent down. Only too often in the past has the tallow been allowed to become contaminated with material obtained from previous casts.

The lead can only produce a very small quantity of the material lying on the surface of the sea bed, unless the latter is soft. For this reason it is not a very efficient sampling device. The grab, described in Section 51 below, is more efficient but much more expensive. An instrument which can be used from a moving boat to bring up a reasonably large sample quickly and easily is badly needed.

50. Sampling from a Ship with an Underway Sampler

Various devices have been made to enable a ship to obtain samples underway. Most of them consist of some form of scoop, which will bring up an ounce or two of material from depths of about 20 fathoms when streamed from a ship moving at 15 knots.

Fig. 3–56 shows a typical simple underway sampler, which works well if it is properly handled. It has no moving parts,* and is easy to construct on board. It is made from steel tube, filled with lead, or solid bar. The sample cup screws on to the front of the main body. The fins may be bolted or welded; if in doubt it is better to make them too big to start with; they should be fairly long. The centre of gravity of the sampler should be at about the point *x*. The towing lug can be adjusted along the T section bar welded to the top of the main body, and locked in the best position with a bolt. The streaming lugs are useful, but not absolutely essential; a soft metal pin may be inserted between them to hold the lowering wire at a point level with or just aft of the centre of gravity when the sampler is streamed; this helps to ensure that it falls quickly to the bottom. When it strikes the pin shears, and the point of tow is transferred to the towing lug for recovery.

UNDERWAY SAMPLER

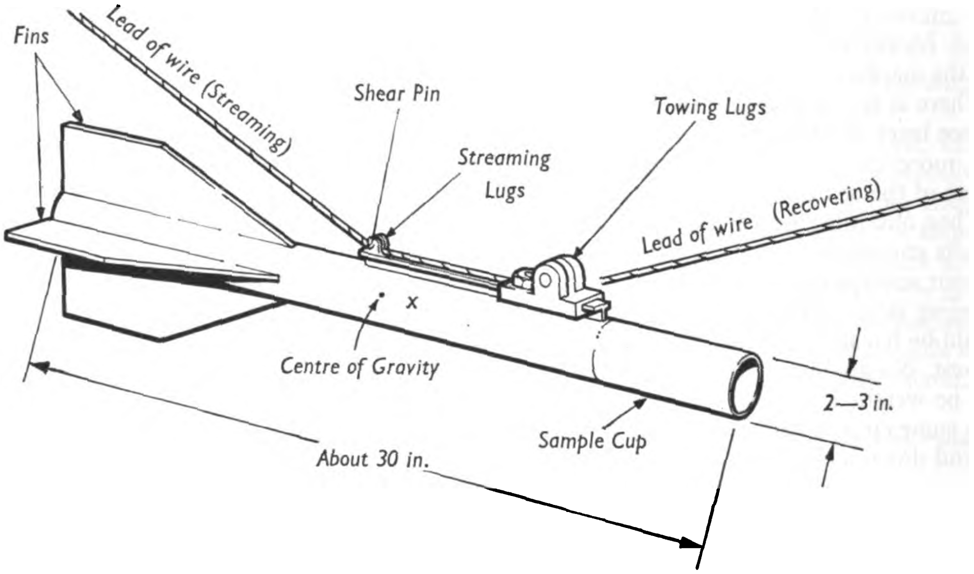


Fig. 3–56

If the streaming lugs are not fitted, the adjustment of the towing lug along the T bar becomes fairly critical. It must be far enough aft to ensure that the instrument drops quickly to the bottom when it is streamed, but not too far aft, or the sampler will overturn as it strikes the bottom, and the sample will be lost, or perhaps not collected at all. The adjustment is best made in the field; it will probably vary from ship to ship.

The sampler may be streamed from a sounding machine, on the normal seven stranded sounding wire; or better still from a more robust winch fitted with oceanographic wire. It is essential that the winch or sounding machine should run out quite freely, so that the sampler is not towed forward by the ship as it falls to the bottom. Many failures to procure a sample are caused by the wire not running out with complete freedom. At speeds of about 10 knots and in 20 fathoms of water it may well be necessary to pay out over 100 fathoms of wire before the sampler reaches the bottom. Experience is necessary to determine when the sampler strikes the bottom; the most reliable indication is probably the amount of wire out. Once it has reached the bottom the motor should be clutched in, and it should then be recovered as quickly as possible.

---

* The fewer moving parts there are the better. Some samplers have a system of levers and hinged covers to retain the sample once it has been obtained. They work beautifully in the workshop, but usually not so well after several descents to the bottom. They are also expensive things to lose when the wire parts, as it will from time to time.

Many samples are lost by bad management of the machine as the sampler breaks surface. It must not be allowed to dance about on the surface for long as it comes up abreast the ship; the machine must be kept heaving in at full speed until the last moment. Some practice and not a little skill is required if the sampler is to be lifted from the water quickly without going through the leading block a fraction of a second later.

51. Sampling with a Grab or Simple Corer

Fig. 3-57(a) shows a typical grab, which may be used to bring up a bottom sample to a vessel which is not moving. It may be screwed into the base of a sounding lead. When the grab strikes the bottom a triggering device operates automatically, and the spring closes the cups to collect a sample. The correct operation of the grab usually depends on the setting of the adjusting nut, which varies the tension on the spring; this setting is fairly critical; if it is incorrect the grab may close as it strikes the water on being lowered, or may not close at all. Grabs, which are comparatively expensive instruments, are made in several sizes, to bring up anything from a few ounces to several pounds. They are easier and quicker to operate than the dredges referred to below, but do not produce so much material. Where the bottom material is granular, a grab may not be able to close properly, and its contents may be lost for this reason.

The simple corer illustrated in Fig. 3-57(b) consists of a streamlined lead weight, with a

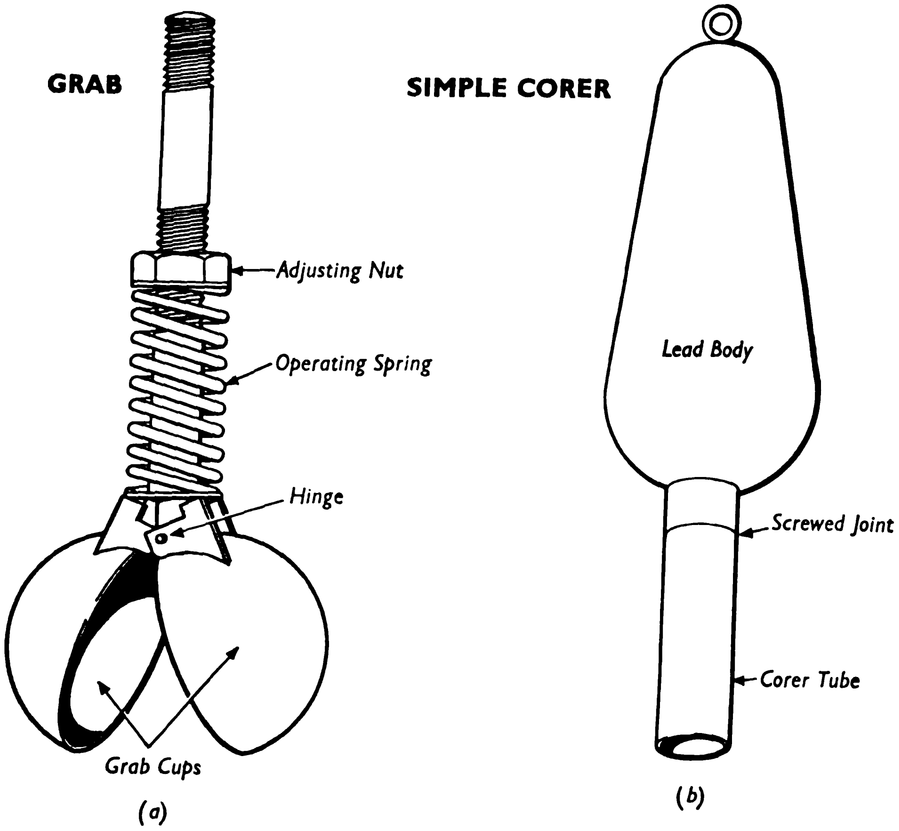


Fig. 3-57

detachable tube fitted to its nose. If it is lowered to within about 20 feet of the bottom and then dropped, it will usually bring up a core sample, whose length will depend on the nature of the bottom material. Fins may be fitted to the lead body of the corer, if desired; they do not, however, improve its performance very much, and are not necessary for general work of a simple nature. If a liner tube, which may be removed with the core undisturbed inside it, can be fitted inside the main corer tube, so much the better; it might well be made of transparent plastic material. A special valve, fitted in the head of the corer tube to prevent a fluid or granular sample slipping out as the corer is recovered, is also an asset. These devices, although desirable, are by no means essential for recovering short cores from fairly shallow water. If possible the coring tube should be made of hard steel, as it is subject to much wear in use. Alternatively a hardened steel cutting head might be fitted to a mild steel tube.

Simple corers do not work well when the bottom consists of stones, pebbles, or coarse sand; such materials are best recovered by dredge or grab. They may, or may not, bring up a sample of fine sand, depending on circumstances, but can be relied upon to produce excellent samples where the bottom consists of mud or clay, or some other plastic substance.

52. Sampling with a Dredge

A simple dredge consists of a stout canvas bag laced inside a conical steel frame, and a three or four legged chain towing bridle. For boat work the mouth of the dredge should be a foot or less in diameter; a ship's dredge could well be about two feet across the mouth. The canvas bag may be replaced by a stout net of any suitable gauge, or have a wire screen placed across an opening in its after end, if it is desired to bring up only the larger particles on the bottom.

If a dredge is to be used on a rough bottom, a weak link should be fitted just above the bridle, with a preventer wire leading from a point above the weak line to the tail of the dredge. If the dredge then fouls, the weak link will part, and the preventer line will dump its contents and enable it to be recovered.

The bridle of a boat's dredge should be attached to a length of cordage, which can be worked easily by hand. In a ship it is often convenient to use a minesweeping wire and winch, if one is fitted. A wire towing pendant, and a winch or capstan of some sort are necessary in any case, unless the dredge is very small.

To use a dredge proceed as follows:

(1) Stop the vessel in the water, heading down wind or down tide if the dredge is streamed over the stern, and in the opposite direction if it is worked from the bows. In a strong tideway it may be prudent to stem the tide, and work the dredge from forward.

(2) Stream the dredge, and veer from three to four times the depth of water on the pendant.

(3) Drift with the wind or tide for a short time, or use the main engines very gently, before recovering the dredge. In most cases it will collect a good sample of the bottom in about five minutes.

The dredge is the best of all the devices available to the surveyor for collecting samples from the top layers of the sea bed. Its use is, however, much more time consuming than that of the other devices mentioned above.

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Table for Converting Metres to Feet and Fathoms

Metres	Feet	Fms.	Metres	Feet	Fms.	Metres	Feet	Fms.
1	3·281	0·547	51	167·323	27·887	200	656·17	109·36
2	6·562	1·094	52	170·604	28·434	300	984·25	164·04
3	9·843	1·640	53	173·885	28·981	400	1312·34	218·72
4	13·123	2·187	54	177·165	29·528	500	1640·42	273·40
5	16·404	2·734	55	180·446	30·074	600	1968·50	328·08
6	19·685	3·281	56	183·727	30·621	700	2296·59	382·76
7	22·966	3·828	57	187·008	31·168	800	2624·67	437·45
8	26·247	4·374	58	190·289	31·715	900	2952·76	492·13
9	29·528	4·921	59	193·570	32·262	1000	3280·84	546·81
10	32·808	5·468	60	196·850	32·808	2000	6561·68	1093·61
11	36·089	6·015	61	200·131	33·355	3000	9842·52	1640·42
12	39·370	6·562	62	203·412	33·902	4000	13123·36	2187·23
13	42·651	7·108	63	206·693	34·449	5000	16404·20	2734·03
14	45·932	7·655	64	209·974	34·996	6000	19685·04	3280·84
15	49·213	8·202	65	213·255	35·542	7000	22965·88	3827·65
16	52·493	8·749	66	216·535	36·089	8000	26246·72	4374·45
17	55·774	9·296	67	219·816	36·636	9000	29527·56	4921·26
18	59·055	9·843	68	223·097	37·183	10000	32808·40	5468·07
19	62·336	10·389	69	226·378	37·730			
20	65·617	10·936	70	229·659	38·276			
21	68·898	11·483	71	232·940	38·823			
22	72·178	12·030	72	236·220	39·370			
23	75·459	12·577	73	239·501	39·917			
24	78·740	13·123	74	242·782	40·464			
25	82·021	13·670	75	246·063	41·010			
26	85·302	14·217	76	249·344	41·557			
27	88·583	14·764	77	252·625	42·104			
28	91·864	15·311	78	255·906	42·651			
29	95·144	15·857	79	259·186	43·198			
30	98·425	16·404	80	262·467	43·745			
31	101·706	16·951	81	265·748	44·291			
32	104·987	17·498	82	269·029	44·838			
33	108·268	18·045	83	272·310	45·385			
34	111·549	18·591	84	275·591	45·932			
35	114·829	19·138	85	278·871	46·479			
36	118·110	19·685	86	282·152	47·025			
37	121·391	20·232	87	285·433	47·572			
38	124·672	20·779	88	288·714	48·119			
39	127·953	21·325	89	291·995	48·666			
40	131·234	21·872	90	295·276	49·213			
41	134·514	22·419	91	298·556	49·759			
42	137·795	22·966	92	301·837	50·306			
43	141·076	23·513	93	305·118	50·853			
44	144·357	24·059	94	308·399	51·400			
45	147·638	24·606	95	311·680	51·947			
46	150·919	25·153	96	314·961	52·493			
47	154·199	25·700	97	318·241	53·040			
48	157·480	26·247	98	321·522	53·587			
49	160·761	26·794	99	324·803	54·134			
50	164·042	27·340	100	328·084	54·681			

Metres	Inches
0·10	3·937
0·20	7·874
0·30	11·811
0·40	15·748
0·50	19·685
0·60	23·622
0·70	27·559
0·80	31·496
0·90	35·433
1·00	39·370

Factors: 1 metre = 3·280839895 feet or 39·370078740 inches
= 0·546806649 fathoms

N.P.134 b (4)

ADMIRALTY MANUAL OF HYDROGRAPHIC SURVEYING

VOLUME TWO

CHAPTER 4

Sweeping and Diving

1969

Published by

THE HYDROGRAPHER OF THE NAVY
TAUNTON, SOMERSET

TABLE FOR CONVERTING FEET AND FATHOMS TO METRES

Feet	Fms.	Metres
1		0·305
1·5	¼	0·457
2		0·610
3	½	0·914
4		1·219
4·5	¾	1·372
5		1·524
6	1	1·829
7		2·134
8		2·438
9	1½	2·743
10		3·048
11		3·353
12	2	3·658
13		3·962
14		4·267
15	2½	4·572
16		4·877
17		5·182
18	3	5·486
19		5·791
20		6·096
21	3½	6·401
22		6·706
23		7·010
24	4	7·315
25		7·620
26		7·925
27	4½	8·230
28		8·534
29		8·839
30	5	9·144
31		9·449
32		9·754
33	5½	10·058
34		10·363
35		10·668
36	6	10·973
37		11·278
38		11·582
39	6½	11·887
40		12·192
41		12·497
42	7	12·802
43		13·106
44		13·411
45	7½	13·716
46		14·021
47		14·326
48	8	14·630
49		14·935
50		15·240

Feet	Fms.	Metres
51	8½	15·545
52		15·850
53		16·154
54	9	16·549
55		16·764
56		17·069
57	9½	17·374
58		17·678
59		17·983
60	10	18·288
61		18·593
62		18·898
63	10½	19·202
64		19·507
65		19·812
66	11	20·117
67		20·422
68		20·726
69	11½	21·031
70		21·336
71		21·641
72	12	21·946
73		22·250
74		22·555
75	12½	22 860
76		23·165
77		23·470
78	13	23·774
79		24·079
80		24·384
81	13½	24·689
82		24·994
83		25·298
84	14	25·603
85		25·908
86		26·213
87	14½	26·518
88		26·822
89		27·127
90	15	27·432
91		27·737
92		28·042
93	15½	28·346
94		28·651
95		28·956
96	16	29·261
97		29·566
98		29·870
99	16½	30·175
100		30·480

Feet	Fms.	Metres
102	17	31·090
108	18	32·918
114	19	34·747
120	20	36·576
126	21	38·405
132	22	40·234
138	23	42·062
144	24	43·891
150	25	45·720
156	26	47·549
162	27	49·378
168	28	51·206
174	29	53·035
180	30	54·864
186	31	56·693
192	32	58·522
198	33	60·350
204	34	62·179
210	35	64·008
216	36	65·837
222	37	67·666
228	38	69·494
234	39	71·323
240	40	73·152
246	41	74·981
252	42	76·810
258	43	78·638
264	44	80·467
270	45	82·296
276	46	84·125
282	47	85·954
288	48	87·782
294	49	89·611
300	50	91·440
306	51	93·269
312	52	95·098
318	53	96·926
324	54	98·755
330	55	100·584
336	56	102·413
342	57	104·242
348	58	106·070
354	59	107·899
360	60	109·728
366	61	111·557
372	62	113·386
378	63	115·214
384	64	117·043
390	65	118·872
396	66	120·701
402	67	122·530
408	68	124·358
414	69	126·187
420	70	128·016

Feet	Fms.	Metres
426	71	129·845
432	72	131·674
438	73	133·502
444	74	135·331
450	75	137·160
456	76	138·989
462	77	140·818
468	78	142·646
474	79	144·475
480	80	146·304
486	81	148·133
492	82	149·962
498	83	151·790
504	84	153·619
510	85	155·448
516	86	157·277
522	87	159·106
528	88	160·934
534	89	162·763
540	90	164·592
546	91	166·421
552	92	168·250
558	93	170·078
564	94	171·907
570	95	173·736
576	96	175·565
582	97	177·394
588	98	179·222
594	99	181·051
600	100	182·880

Feet	Metres
700	213·360
800	243·840
900	274·320
1000	304·800

Fms.	Metres
200	365·760
300	548·640
400	731·520
500	914·400
600	1097·280
700	1280·160
800	1463·040
900	1645·920
1000	1828·800

Inches	Ft.	Metres
1	0·083	0·025
2	0·167	0·051
3	0·250	0·076
4	0·333	0·102
5	0·417	0·127
6	0·500	0·152

Inches	Ft.	Metres
7	0·583	0·178
8	0·667	0·203
9	0·750	0·229
10	0·833	0·254
11	0·917	0·279
12	1·000	0·305

Factors

1 Inch = 0·0254 metres
1 Foot = 0·3048 metres
1 Fathom = 1·8288 metres
or 6 feet

N.P.134 b (4)

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59		17·983
60	10	18·288
61		18·593
62		18·898
63	10½	19·202
64		19·507
65		19·812
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78	13	23·774
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80		24·384
81	13½	24·689
82		24·994
83		25·298
84	14	25·603
85		25·908
86		26·213
87	14½	26·518
88		26·822
89		27·127
90	15	27·432
91		27·737
92		28·042
93	15½	28·346
94		28·651
95		28·956
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228	38	69·494
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294	49	89·611
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312	52	95·098
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330	55	100·584
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468	78	142·646
474	79	144·475
480	80	146·304
486	81	148·133
492	82	149·962
498	83	151·790
504	84	153·619
510	85	155·448
516	86	157·277
522	87	159·106
528	88	160·934
534	89	162·763
540	90	164·592
546	91	166·421
552	92	168·250
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Inches	Ft.	Metres
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8	0·667	0·203
9	0·750	0·229
10	0·833	0·254
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or 6 feet

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Published by

THE HYDROGRAPHER OF THE NAVY

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This Chapter supersedes the whole of Chapter XI of the *Admiralty Manual of Hydrographic Surveying* (1948 Edition).

Price 10*s*. 0*d*.

Printed in England for Her Majesty's Stationery Office
by The Campfield Press, St. Albans

FOREWORD

The surveyor uses his sweeping gear to detect and establish the least depth over wrecks and other dangers to navigation.

Part of this chapter deals with the principles and practice of Sonar Sweeping, which at the present time is suited more to the detection of dangers than to the finding of the least depth over them.

Part Two covers the use of the Oropesa Sweep, which may be used to detect and find the least depth over a danger to navigation, or to establish a clear depth in a channel.

Drift and Drag Sweeping, which is dealt with in Part Three, is particularly suited to the determination of the least depth over a wreck, obstruction or other relatively small areas.

The use of free divers in surveying is described in Part Four.

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CHAPTER 4

Sweeping and Diving

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CHAPTER 4 *Sweeping and Diving*

Part 1 Sonar Sweeping

1. Introduction

When an area has been sounded out by the methods described in Chapter 3, the surveyor will be able to depict the contours of the sea bed on his sounding tracing. Provided all indications of shoal water have been properly investigated it is not very likely that any natural dangers to navigation will have been missed, unless these are small and rise abruptly from the sea bed between adjacent lines of sounding.

It is quite possible when sounding, however, to fail to detect small but dangerous coral knobs or pinnacle rocks, even on comparatively large scales. Wrecks and other man-made dangers to navigation can also often lie undetected between lines of soundings, unless their positions are accurately known beforehand.

For these reasons no original survey should be considered to be complete unless the sounding is backed up where necessary by some form of sweeping.

It should very seldom be necessary to sweep in waters deeper than 100 fathoms (see Section 44 of Chapter 3). In coral infested water it might well be prudent to sweep as much as possible of the area within the 100 fathom line. Where coral cannot grow judgement and prudence must still be exercised; in most cases the 40 to 50 fathom lines will form a reasonable limit.

The types of sweep available to the surveyor (in1968) are set out below, with brief notes on their use and usefulness. Diving operations are included here since they are often carried out on wrecks or shoals.

a. The sonar sweep

A sonar sweep may be carried out comparatively easily and quickly. The sonar beam, being projected more or less horizontally, should detect objects rising from the sea bed between lines of soundings. However, the propagation of the beam is affected by water conditions, and the safe working range of a sonar set can be very short in really adverse conditions. For this reason this type of sweeping is not infallible. Nevertheless, a careful sonar sweep, carried out in accordance with the instructions given in Part 1 of this chapter, should greatly reduce the possibility of a danger to navigation lying undetected on the sea bed.

b. The oropesa wire sweep

When an area has been swept by the oropesa sweep the surveyor may be confident that no danger to navigation can rise from the bottom above the depth at which the sweep actually ran. The depth keeping qualities of the sweep are not particularly good, being of the order of ±1 fathom. However, it may be towed at a comparatively high speed through the water, sweeps a fairly wide path, and is particularly suitable for obtaining positive clearance depths in channels where the surveyor has reason to believe that obstructions are not too numerous. The sweeping vessel must be fairly powerful, and will require plenty of sea room when turning with the sweep set. An oropesa sweep should not be run too near the bottom; two fathoms is a reasonable minimum safe clearance.

c. Drift and wire drag sweeps

Drift and wire drag sweeps provide positive evidence that no danger can rise from the sea bed above the depth at which they ran. Their depth keeping qualities will vary from ±1 to perhaps ±6 feet, depending on how they are used. They must be towed very slowly, or even perhaps remain virtually still in the water, making use of the tidal stream or wind drift. They are particularly suited for use in confined waters, and to the accurate sweeping of wrecks, coral knobs or pinnacle rocks whose positions are well known. They cover the ground very much more slowly, yet with greater depth keeping accuracy, than the oropesa sweep, and may be run within a foot or two of the bottom; they are also very suitable for obtaining a definite least depth over an obstruction by fouling and clearing.

d. Diving operations

Diving operations will pay the highest dividends when the object under investigation has been accurately fixed, and lies in reasonably clear and still water. A competent diver can not only find the least water over an object on the bottom, but also bring back an intelligent report of what he saw and felt. His report may, for instance, provide the only evidence that an object under investigation is in fact a wreck (position approximate) reported to lie some distance away. In one case such a wreck was eventually found nearly five miles from its reported position, and positively identified both by its own characteristics and the cargo of 3-ton trucks it was carrying when it sank.

2. Basic Principles

A sonar set projects a powerful beam of acoustic energy horizontally into the water. Usually the beam is cone shaped, and its apex angle varies between about 10° and 15°.

The transducers of most sonar sets can be trained in a horizontal direction, and an experienced operator can obtain bearings of returning sonar echoes accurate to within two or three degrees. For surveying work it will be an asset if a gyro or transmitting magnetic compass output can be fed into the sonar controlling device, so that these bearings will be true, and not relative to a possibly changing ship's head. In many sets it is possible to vary the transmission repetition frequency at will; the faster the repetition frequency the shorter will be the working range, but the less time will it take to sweep in steps over a given arc.

The range of a sonar set depends very much on the frequency of the transmitted acoustic energy and the nature of the water through which this energy is passing, and to a lesser extent on the nature of the sea bed and the state of the sea surface. Sets operating on frequencies between 12 kc/s and 25 kc/s have a working range of at least 2,000 yards under good conditions. As the frequency is raised much above 25 kc/s the working range will decrease.

All sonar sets measure the time taken for the acoustic pulse to proceed to and return from a target. Most of them convert this time interval automatically into distance, assuming a fixed value for the speed of sound in water. This process is exactly the same as that carried out by an echo sounder measuring depths.

a. The effect of water conditions

When travelling more or less horizontally through water a pulse of sound energy will always seek out the level at which the speed of sound in water is least, proceed to that level, and stay there if it possibly can.* This effect has a great influence on the behaviour of a sonar set. Imagine that the ship in Fig. 4.1, is fitted with a very special sonar set which transmits an extremely narrow beam in the required direction only. She is hoping to detect a wreck lying on the sea bed.

In (*a*) the velocity of sound in water remains constant with depth. The sonar beam will therefore travel in a straight line from the transducer A to the wreck B and back, and an 'echo' from the wreck will be obtained. These conditions are perfect, and are not very likely to be encountered in practice.

In (*b*) the velocity of sound in water decreases steadily with depth, being a minimum on the sea bed. The outgoing energy will be refracted downwards, proceeding along the firm line from A to B. However, energy returning from the wreck will tend to stay at a depth where the velocity of sound is least; it will therefore hug the bottom and no echo will be received in the ship.

In (*c*) the velocity of sound increases steadily with depth, being a maximum on the sea bed. The outgoing energy must therefore start at a steep angle of depression if it is to strike the wreck at all, it will proceed, as before, along the firm line. Returning energy will proceed rapidly to the surface, and stay there. There ought, therefore, to be a fairly good echo.

In (*d*) the velocity of sound is least in a layer of water about half-way between the surface and the bottom. Outgoing energy will be refracted into this layer, and will then tend to stay in it; it will therefore pass over the wreck. If any of it does manage to penetrate the layer to the wreck, the reflected energy will proceed back along the pecked line, and pass under the ship. There will therefore be no echo in the ship.

In practice a sonar set transmits simultaneously a great number of the rays depicted in the figure; taken together these form the sonar beam. Some of them will probably strike the wreck and return to the ship whatever the water conditions may be, since changes in the velocity of sound in water do not take place in the simple manner described above. However if the conditions are bad the sonar pulse will certainly be attentuated, and the range of the equipment may be reduced very much indeed.

The velocity of sound in water depends mainly on the water temperature. A bathythermograph observation can therefore be of the greatest assistance to the surveyor wishing to determine sonar operating conditions. It should be remembered that velocity increases with depth, increasing salinity, and increasing temperature.

b. Shadow effect; nature of the target

If a bank or sandwave rises from the bottom between the sonar set and a wreck, the latter may lie partially in the former's shadow, and an echo from it may be weakened, or in extreme cases lost entirely. The surveyor should bear this point in mind when sonar sweeping for wrecks, and if necessary plan his search so that each area of sea bed is examined from more than one direction.

Wrecks are sometimes canted over at an angle, or lie in a scour which has been formed by the tidal stream. In these cases they will almost certainly give a really good echo from one direction only. When examined from other directions they may well fail to give an echo at all. It seems that the rate and direction of the tidal stream itself may have something to do with this effect.

c. Automatic gain control; noise and interference

Most sonar sets are designed primarily to detect submarines; their outputs feed a recording device similar to the recorder of an echo sounder, and one or more loudspeakers and headphones. The submarine hunter is concerned mainly to determine

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* Both sound and light waves are always refracted in a direction which will cause them to settle down in a layer or duct where their velocity is least.

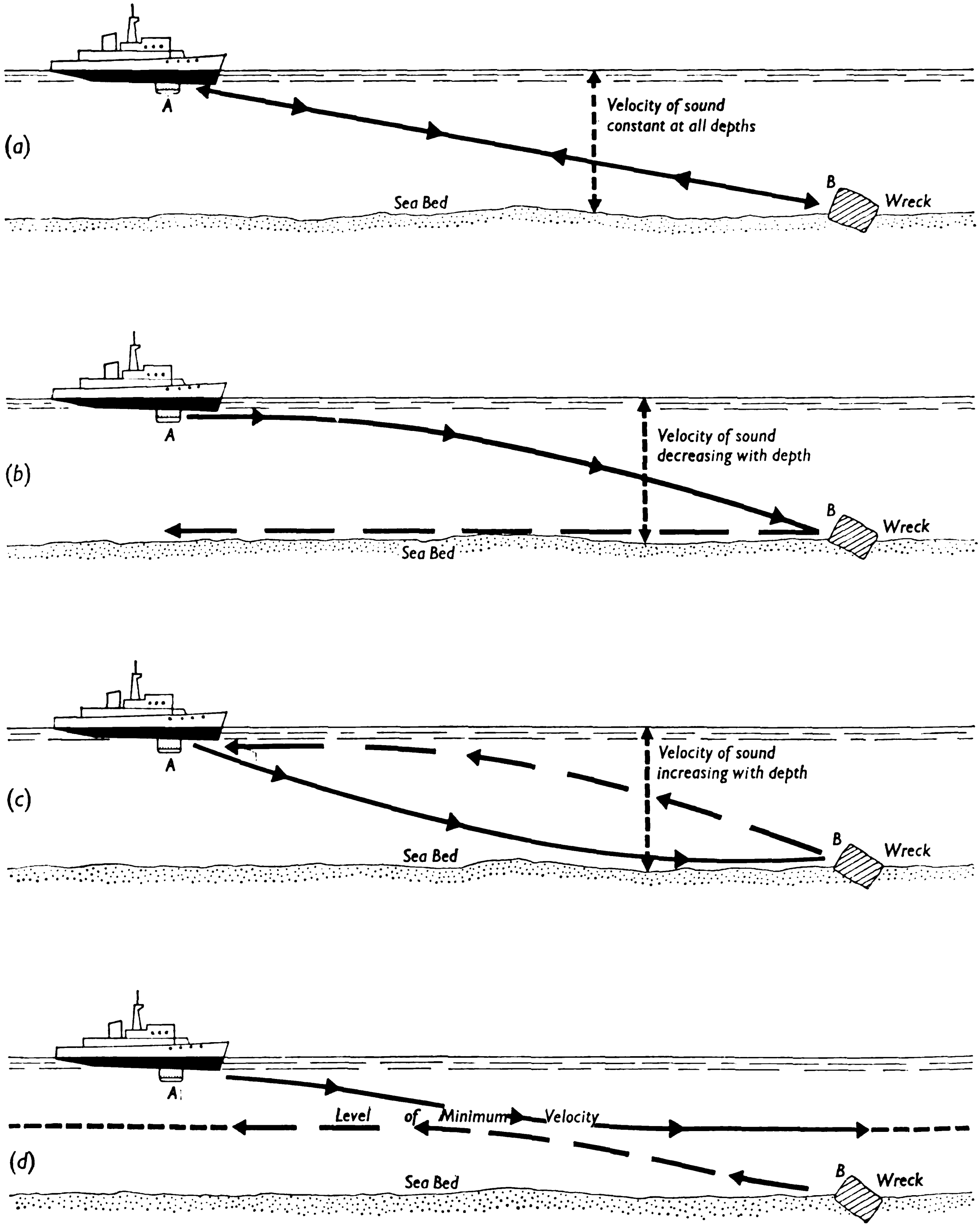
A
(a)
Velocity of sound constant at all depths
B
Wreck
Sea Bed
A
(b)
Velocity of sound decreasing with depth
B
Wreck
Sea Bed
A
(c)
Velocity of sound increasing with depth
B
Wreck
Sea Bed
A
Level of Minimum Velocity
(d)
B
Wreck
Sea Bed

Fig. 4–1

whether an echo is a submarine, and then to attack it in the most efficient way. He is not too concerned with delicate changes in the quality of the echo. The surveyor, on the other hand, is generally very concerned with the quality of a returning echo; a trained and experienced ear, provided it is not tone deaf, can learn a great deal from listening to the returning echoes in headphones or by loudspeaker. Since the quality of the returning echo is so important to the surveyor, and since his sonar set will not generally have been designed specifically for the purposes for which he is using it, it becomes necessary to consider how this quality may be affected by noise and interference.

(i) Automatic gain control. The receivers of most sonar sets are fitted with automatic gain control circuits. These circuits operate in such a way that the amplification, or gain of the receiver varies, depending on the strength of the received signal. The weaker the signal, the greater is the automatic gain. In this way the output of the receivers is automatically controlled at a convenient level. In most cases the A.G.C. circuit responds only to signals which last longer than a certain (fairly short) time. A powerful return echo will always get through the circuit at full strength, provided it lasts less than one-tenth of a second or so; if it lasts longer than this its tail end will be artificially attenuated in the receiver. The level of the gain in the receiver will normally be determined by the background noise present during the reception period. Loud reverberations, water noises, or indeed any continuous noise, will automatically reduce the gain, so that the output remains fairly constant; a wanted signal will then have to be appreciably stronger than this background level if it is to stand out above it. Automatic gain does not operate in most sets unless they are transmitting.

All these things are generally built into a particular set. They are very desirable to the man looking for submarines, but not always quite so desirable to the surveyor searching for wrecks and obstructions on the sea bed.

(ii) Natural noise and interference. Natural noise and interference may be defined as that over which the surveyor in the field has no control.

Sonar sets, and their A.G.C. circuits, are very sensitive to water borne noises of all sorts. Quenching, which results in bubbles of air or water vapour passing through the sonar beam close to the transducer, may be caused by pitching, or by a badly faired hull in the vicinity of the transducer. It creates a sound of rushing water in sonar headphones. It will always cause the A.G.C. circuits to reduce the sensitivity of the receiver, and if it becomes too bad it may well obliterate even the strongest of returning echoes. Quenching can be lessened by reducing the pitching motion of a ship, perhaps by reducing speed, and by giving careful attention to the fairing of the hull in the area around the transducer. In many cases it depends almost entirely on the weather.

A ship's propellors cause noise, which can be heard with a sonar set when the transducer is trained aft of the beam. If this noise is present the A.G.C. circuits will automatically reduce the gain of the receiver, and an echo which otherwise would be heard, may be lost. Badly pitted or damaged blades on a propellor can cause sufficient noise to make it very difficult to use a sonar set at all.

A sonar beam will generally be reflected back off the sea bed and by particles of suspended matter in the water. Under good operating conditions these reflections, which are known as Reverberations, can be heard out to quite considerable ranges. They help the surveyor to assess the operating conditions, and are therefore very useful. However, it must not be forgotten that the A.G.C. in most sets will always modify their true nature, so that signals greater in strength than a certain level will be attenuated. It will always be useful if the surveyor can listen to the reverberations with the A.G.C. inoperative, before starting to sweep, in order to assess their real quality; unfortunately with most sets the A.G.C. cannot easily be switched off.

(iii) Man-made noise and interference; the effect of echo sounders on sonar. Man-made noise and interference may be defined as that over which the surveyor in the field has complete or partial control.

Any sound signal transmitted into the water will be picked up by a sonar set if its frequency is anywhere near that of the set. Machinery of all sorts, if not properly insulated from the outer hull of the ship, can cause interference. It may well in certain circumstances cause the A.G.C. circuit in the receiver to reduce the sensitivity of the set. The interference may not appear to be very loud in the headphones or loudspeaker, since it is being attentuated; but so is the very echo which the surveyor is hoping to hear.

The average echo sounder, transmitting in the feet scale on a frequency similar to that of a sonar set, creates a loud banging noise every half second or so; this noise is not likely to be attenuated by the A.G.C. circuit in the sonar receiver; it makes the sonar operator's task difficult and tiring. If the echo sounder is switched to the fathoms scale the bangs will be less frequent (every 2½ seconds or so) but just as loud. Experience indicates that the echo sounder and sonar frequencies must be separated by several kc/s,* before this type of noise is reduced to a level which does not cause distress to the sonar operator.

Well informed opinion varies as to whether or not the noise created by an echo sounder working on a similar frequency destroys the efficacy of a sonar set which is being used for wreck sweeping. Some surveyors sound and sweep for wrecks at the same time; others are convinced that such a practice is dangerous, maintaining that the sonar operator will not be able to listen properly for returning echoes for more than a few minutes at a time.

Each surveyor must come to his own conclusion. If any doubt exists in his mind, however, a desire to produce results quickly must be tempered by prudence.

d. Determining sonar operating conditions in the field

The determination of sonar operating conditions in the field is not at all easy. It is more of an art than a science, and experience is probably the best weapon available. The points set out below may be helpful:

(i) Assessment on a known wreck. The surest way to assess operating conditions is probably to transmit at a wreck, where position and nature are known. A coral knob or pinnacle rock may be used for the same purpose. The range at which it can be detected with certainty can be noted.

Unfortunately suitable wrecks and rocks do not generally lie in convenient positions, and the method can seldom be used.

(ii) Using a bathythermograph. If a bathythermograph is lowered to the bottom in the sweeping area, it will bring back a record of temperature plotted against depth. This record can be of great assistance in assessing the operating conditions. (See Section 2**a** above). The conditions shown in Fig. 4–1(*a*) will exist when the temperature falls evenly and very slightly† with depth, since the effect of the fall of temperature will be balanced by that of increasing pressure, to give a constant velocity of sound in all depths. If the temperature decreases rapidly with depth, or there is an inversion of the temperature gradient, the conditions shown in Fig. 4–1(*b*) and (*d*) will probably apply, and the sonar set cannot be expected to work well.

(iii) Listening to reverberations and bottom echoes. If the operating conditions are good a well adjusted sonar set will produce reverberations which continue for some time after each transmission. These must not be judged solely by their volume, which in most sets will be controlled at a steady level by the A.G.C. circuit, whatever the conditions; the longer they can be heard, and the more resonant they are, the better will be the operating conditions. If possible, it will always be helpful to listen to the reverberations with the A.G.C. switched off, to determine their true nature. When conditions are bad the reverberations will be weak and short lived, and individual transmissions will sound flat and lifeless; in extreme cases there may be no reverberations at all.

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* Two or three kc/s is certainly not enough; five might be and ten almost certainly would be. Harmonics can also cause trouble.

† To maintain a constant velocity of sound the temperature should drop about 0·1° C. per 10 fathoms.

The sea bed is seldom completely flat, and it will very often be possible to obtain sonar echoes off a sand bank or shoal. The better their quality and the greater the distance at which they can be heard, the more favourable will be the operating conditions.

(iv) Changes in operating conditions. It should not be assumed that because operating conditions are favourable at the start of a day's work, they will remain so for the rest of the day.

A tidal stream may replace a body of water completely within an hour or two; the newly arrived water may have quite different properties from the old. Again, a strong sun shining on a calm body of water can easily alter its transmission characteristics (usually for the worse) in a few hours.

The surveyor using a sonar set should therefore constantly be asking himself whether the operating conditions are still as good as they were when he started work. Bathythermograph observations are easy to obtain under way, and they will always help him to answer this question.

3. Practical Sonar Sweeping

It is comparatively easy to state how a sonar sweep should be carried out in theoretically ideal conditions, on the assumption that all objects capable of resolution by the transmitted sonar beam are to be detected. It is virtually impossible to predict how these theoretical rules of procedure must be modified to ensure that nothing is missed, in the conditions in which the typical surveyor in the field will usually find himself.

Suppose, for instance, that the surveyor is required to detect all objects rising more than a foot or two off the sea bed, and assume that the equipment is capable of detecting these objects in ideal conditions. He may proceed on the lines set out below, and will then know that in theory the reliability of his sweep is 100%. But what is the actual reliability of his sweep in the conditions under which it was made and how will this reliability be improved if, say, he sweeps the same area a second time, perhaps running his lines in a direction at right angles to the first set? The answers to these questions can only be arrived at by the application of judgement and experience. The expenditure of valuable time and the need to produce reliable work will always be tugging the surveyor's judgement in opposite directions. If tempted to save time, he should always remember that to sweep an area twice by sonar will still occupy far less time than to sweep it once by any other known method.

In the sub-sections below, it will be assumed to start with that conditions are ideal. In these conditions, rules can be given which will produce the most work in the least time. In the notes which follow, the surveyor may find information which will help him to modify and apply these rules so that the most reliable sweep will be obtained in any particular set of circumstances.

a. Method of sweeping in ideal conditions

When sounding, the surveyor will cover more ground per unit of time, the faster he proceeds. When sonar sweeping this is not necessarily the case. There is a certain speed at which the maximum area per unit of time will be covered.

This speed will depend on the following factors:

(i) The maximum working range of the sonar. The greater this is the faster may the ship proceed, and the more ground will be covered in a given time.

(ii) The minimum detection range of the sonar, inside which objects will pass undetected beneath its beam. This range will depend on the maximum angle of depression of the beam, and either the depth of water or (when the water is very deep) the depth at which an object must be detected. The greater this minimum detection range, the slower will the ship have to proceed.

(iii) The arc swept, and the way in which it is swept. There will be a certain value for the swept arc which will be most advantageous. It must always be swept over from aft to forward.

(iv) The time taken to complete one sweep. Clearly the shorter this time can be the faster may the ship proceed. Sonar sets having wide beam angles in the horizontal plane will be more efficient than those with narrow beams, since their sweeping steps may be bigger.

Figure 4–2 shows a plan view of a ship sonar sweeping. Her course made good (not necessarily her ship's head) is along the line AB; the maximum working range is R; the minimum detection range is r; the arcs swept are from Green and Red α° to 5° on the opposite bow, all relative to the course made good. This slight crossing of the bow at the end of the sweep up each side is important. The effective width of the swept track is $2s$. The points a, b, c and d, indicate the ship's positions at the start of the various sweeps.

This vessel is proceeding as fast as she prudently may in these (very theoretical and perfect) conditions. If she proceeds any faster small unswept areas will appear just above the two potential danger spots. It may seem strange, but the areas most likely to remain unswept will always lie on or close to the ship's track; the cause of this is the minimum detection range r, which, as can be seen in the diagram, creates a slot of unswept water close to the ship's track in each sweep. It is most important that the ratio r/R should be as small as possible; if it becomes large then the sweeping may become impracticable. The overlapping away from the ship's track occurs only because it is vital to prevent gaps being left on or near the track.

Referring to the figure, the practical surveyor wants s to be as great as possible, and he wants the ship's speed to be as great as possible, for on these two factors depends his output of acres swept per hour.

The problem is one of finding the best ship's speed, when α, R, and r (which itself depends on two other variables), and the time taken for one sweep can all be varied. It may be solved most simply in stages, in the following manner:

(i) Solving the sweeping problem, stage 1. Finding the best value for α. Assume for the moment that the minimum detection range is zero, i.e. that the sonar beam can 'see' vertically below the ship.

In Fig. 4–3 the ship is stopped at O, and sweeping in this particular case from Green α° to right ahead, at a rate of ω secs/degree. The maximum working range is R; the swept area is a segment of a circle, and the time taken to complete the sweep up one side is $\alpha\omega$ secs. Since the ship is 'stopped' in this example, the sea bed with all the objects to be detected lying on it must be 'moving' down the parallel pecked lines at her true speed. The immediate problem is to select α so that the product $AY \times YZ$ (which is a direct measure of acres covered per sweep) is as large as possible,* without leaving any gaps in the swept area. The first objects that are going to be missed will be 'travelling' down the lines through X or Y; therefore if the surveyor ensures

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* The maximum value is obtained when $\alpha = 135^\circ$, but this would leave gaps in the sweep.

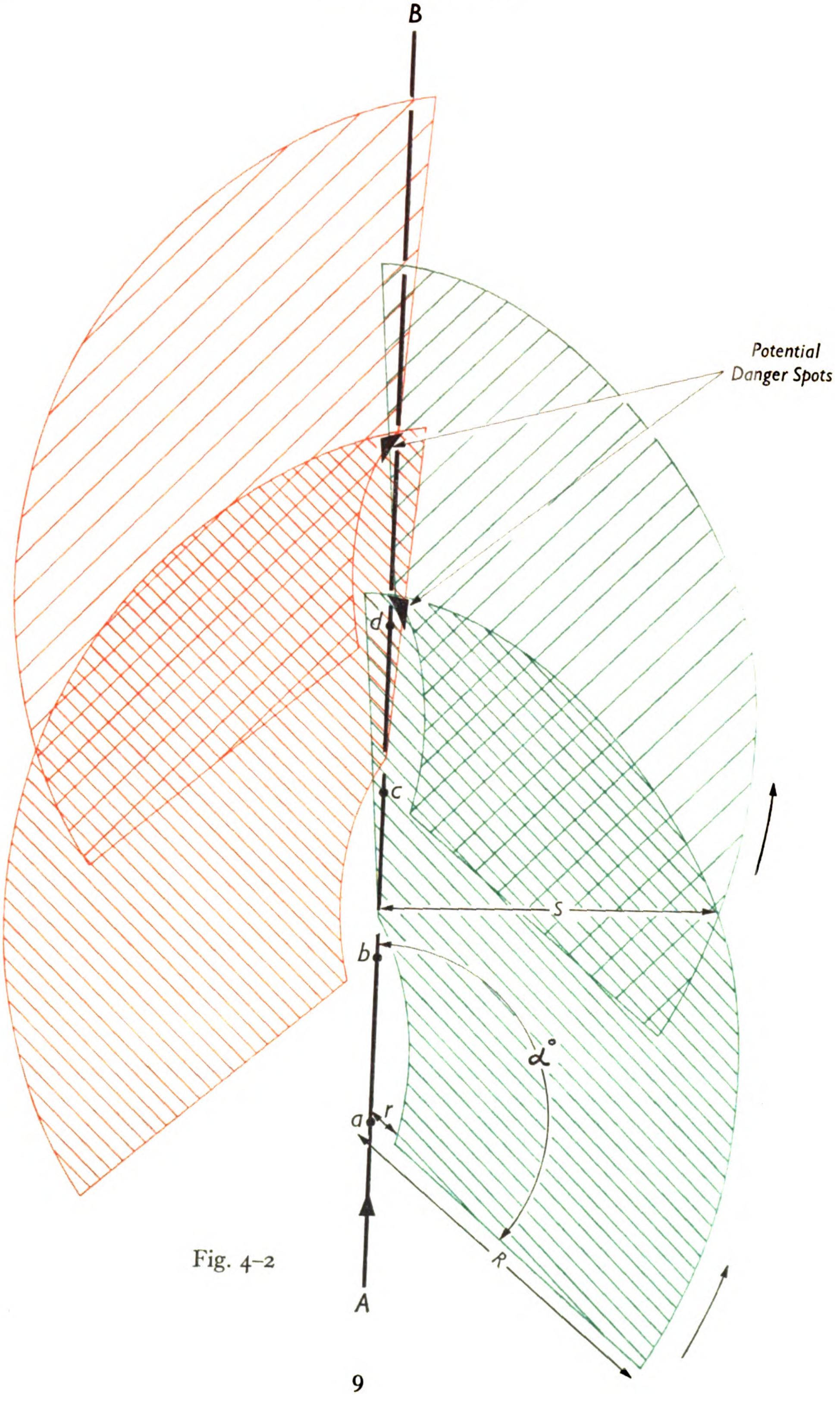


Fig. 4–2

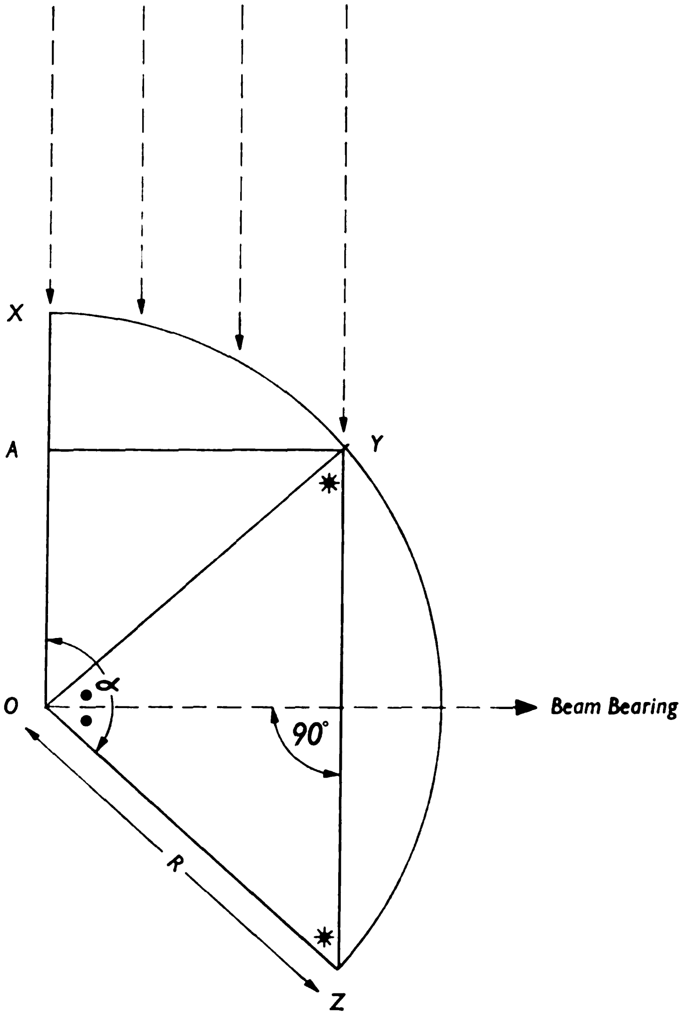


Fig. 4-3

✱ $= 180° - \alpha$

• $= \alpha - 90°$

that all objects travelling down these lines are detected, he may be certain that all others within his swept area will also be detected.

Consider an object moving down the line *XAO*. It arrives at *X* an instant after the sonar has swept along the line *OX*, and is therefore not detected. It must not pass *O* before the sonar, having completed the sweep up the port side, casts its beam along the line *OZ*.

Its maximum speed must therefore be $R/\alpha\omega$.

Now consider an object moving down the line *YZ*, whose length is equal to $2R \cos \alpha$, since the triangle *YOZ* is isosceles. Suppose the sweep starts along the line *OZ* at time 0; then it will reach the line *OY* at a time $(2\alpha - 180)$ secs. An instant after this time the object arrives at *Y*; it is therefore not detected. It must not pass *Z* before the sweep reaches the line *OZ* again. Now the time taken to complete the sweep up the starboard side is $\alpha\omega$, and a similar time must be allowed for the sweep up the port side. Therefore to sweep from the line OY to the line OZ will require a time

$$\begin{aligned} &2\alpha\omega - \omega\,(2\alpha - 180) \text{ secs} \\ &= 2\alpha\omega - 2\alpha\omega + 180 \text{ secs} \\ &= 180 \text{ secs} \end{aligned}$$

During this time the object must not travel a distance greater than YZ, which is equal to $2R \cos \alpha$.

Therefore its maximum speed must be

$$\frac{2R \cos \alpha}{180\,\omega.}$$

Since the speeds of the two objects moving down the lines XO and YZ must be equal, if there are to be no gaps in the swept area,

$$\begin{aligned} R/\alpha\omega &= \frac{2R \cos \alpha,}{180^\circ\,\omega} \\ \alpha\omega\,(2R \cos \alpha) &= 180^\circ\, R\omega, \\ 2\alpha \cos \alpha &= 180^\circ, \\ \alpha \cos \alpha &= 90^\circ, \end{aligned}$$

and $\alpha = 132^\circ\, 45'$ approximately.

For practical purposes it will be more convenient to accept a value of 120° for α.*

When this is done the surveyor has some interesting facts which are pertinent to the solution of the problem of how best to sweep:

(i) The arc swept should always be from Red and Green 120° to (in theory) right ahead but (in practice) to 5° on the opposite bow.

(ii) When this is done the swept path will be equal to $2R \sin 120^\circ = 1{\cdot}73R$.

(iii) The ship's prudent speed will now depend on the time taken to complete one sweep, the maximum working range R, and the minimum detection range r.

(ii) Solving the sweeping problem, stage 2. Finding the equivalent speed u. Still assuming (as in (**i**) above) that the minimum detection range is zero, and with the arc swept over now constant at 120°, an equivalent speed u may be worked out; it will depend on R and the time taken to complete one double sweep.

Referring to Fig 4–3, the speed of an object down YZ (which is the equivalent speed u) is given in (**i**) above, and is

$$u = \frac{2R \cos \alpha.}{180\,\omega}$$

Since $\alpha = 120^\circ$

$$u = \frac{R\alpha}{180\omega}$$

where u is in ft/sec, and R is in feet.

If u is measured in knots and R is in yards,

then $u = \dfrac{1{\cdot}8R}{180\omega.}$

Let the time taken for one complete double sweep be x.

Then $x = 2\alpha\omega = 240\omega$, when $\alpha = 120^\circ$.

---

* This makes the geometry of the figure very simple and provides a slight overlap on ahead bearings where it is most needed.

Therefore, since $180\omega = 3x/4$

$$u = \frac{1{\cdot}8R\times 4}{3x} = \frac{2{\cdot}4R.}{x}$$

Where u is in knots, R is in yards, and x is in seconds.

If the minimum detection range was zero the problem would now be solved, and the equivalent speed u could be tabulated for a fixed sweep of 120°; it would depend, as common sense would indicate, on the maximum working range R, and the time taken to complete one sweep.

Unfortunately the minimum detection range never is zero, and the solution to the problem requires a third step.

(iii) Solving the sweeping problem, stage 3. Finding and allowing for the minimum detection range r. If the maximum angle of depression of a sonar beam is θ, the depth of water, or the depth at which it is required to detect an object is d, and the minimum detection range is r, then

$$r = d \cot \theta.$$

Referring to Fig. 4–2, even if r is as small as one yard there will still be a slot of unswept water running up the ship's track for the whole distance *ab*. In the figure the ship's actual speed v has been adjusted so that the unswept slot in any particular sweep is covered by the previous sweep on the same side. Clearly the governing factor in this situation is the ratio r/R. If R is very large then a moderately large r will have little effect; conversely if the ratio r/R approaches unity, then there will be very little point in sweeping at all, since v will of necessity be very slow indeed.

It may be shown that the actual speed made good v, is related to the equivalent speed u by the formula

$$\frac{v}{u} = \frac{\frac{3}{4}(R-r)}{R}.$$

It can be seen that if $r = R$, $v = 0$. If $r = 0$ the formula breaks down, since in that case v must equal u. However, as soon as r becomes measureable, however small it may be, v cannot exceed $3u/4$.

This completes the solution of the theoretical problem. To sum up, the surveyor:

(i) Finds out the best value of the swept arc α, and then accepts a value (120°) fairly close to it, which errs on the side of safety and makes the mathematics simpler. This chosen value of the swept arc automatically establishes the width of the swept path in terms of R.

(ii) Finds out the equivalent speed u, which varies with R and the time taken to complete one double sweep, assuming that the minimum detection range is zero.

and then

(iii) Modifies u to allow for the fact that r never can be zero, to find v, the speed made good over the ground.

Note that all these courses and speeds are 'made good', and that therefore a tidal stream may make it necessary to apply quite large corrections to the course steered and speed through the water as the sonar sweeping is progressed.

b. Working rules for sonar sweeping

In this sub-section the solutions to the problem, arrived at in **a** above, are reduced to a practical procedure.

To sweep most efficiently proceed as follows:

(i) Relative to the course made good, sweep from Red 120° to Green 5°, Green 120° to Red 5°, and so on. The arc must always be swept over from aft to forward.

(ii) Estimate the maximum working range R, of the sonar. On no account over estimate it. Judgement, experience, and a consideration of the points discussed in Section 2 above will be required.

(iii) Enter the table below with the maximum angle of depression of the sonar beam, and the depth of water or the depth at which it is required to detect an object, and extract the minimum detection range r. If in doubt make this range too big rather than too small.

SONAR SWEEPING. MINIMUM DETECTION RANGE

DEPTH IN FATHOMS	ANGLE OF DEPRESSION AND MINIMUM DETECTION RANGE (YDS.)									
	5°	8°*	10°	15°	20°	25°	30°	35°	40°	45°†
5	114	71	57	37	27	21	17	14	12	10
10	229	142	113	75	55	43	35	29	24	20
15	343	213	170	112	82	64	52	43	36	30
20	457	285	227	149	110	86	69	57	48	40
25	572	356	284	187	137	107	87	71	60	50
30	686	427	340	224	165	129	104	85	72	60
35	800	498	397	261	192	150	121	100	83	70
40	914	569	454	299	220	172	139	114	95	80
45	1,029	640	510	336	247	193	156	129	107	90
50	1,143	712	567	373	275	214	173	143	119	100
55	1,257	783	624	411	302	236	191	157	131	110
60	1,372	854	681	448	330	257	208	171	143	120

* This angle applies to the main beam of Type 164. † This angle applies to the Q2 beam of Type 164.

(iv) Calculate the ratio r/R.

(v) Work out the time that will be occupied in making one complete sweep (Red 120° to Green 5° and then Green 120° to Red 5°). Add to this time an allowance for looking at objects detected during the sweep. Call the total the 'Time for one complete sweep'. If in doubt make it too long, rather than too short.

(vi) Enter Fig. 4-4 with the Time for one complete sweep, the maximum Working Range R, and the ratio r/R, and extract v, the Speed Made Good. In the example in the diagram $r = 356$ yards; this is obtained from the table by entering it with a depression of 8° (Type 164) and a working depth of 25 fathoms. On no account must v be exceeded; if it is there may be holidays in the swept area, and these will occur first on and near the ship's line of advance.

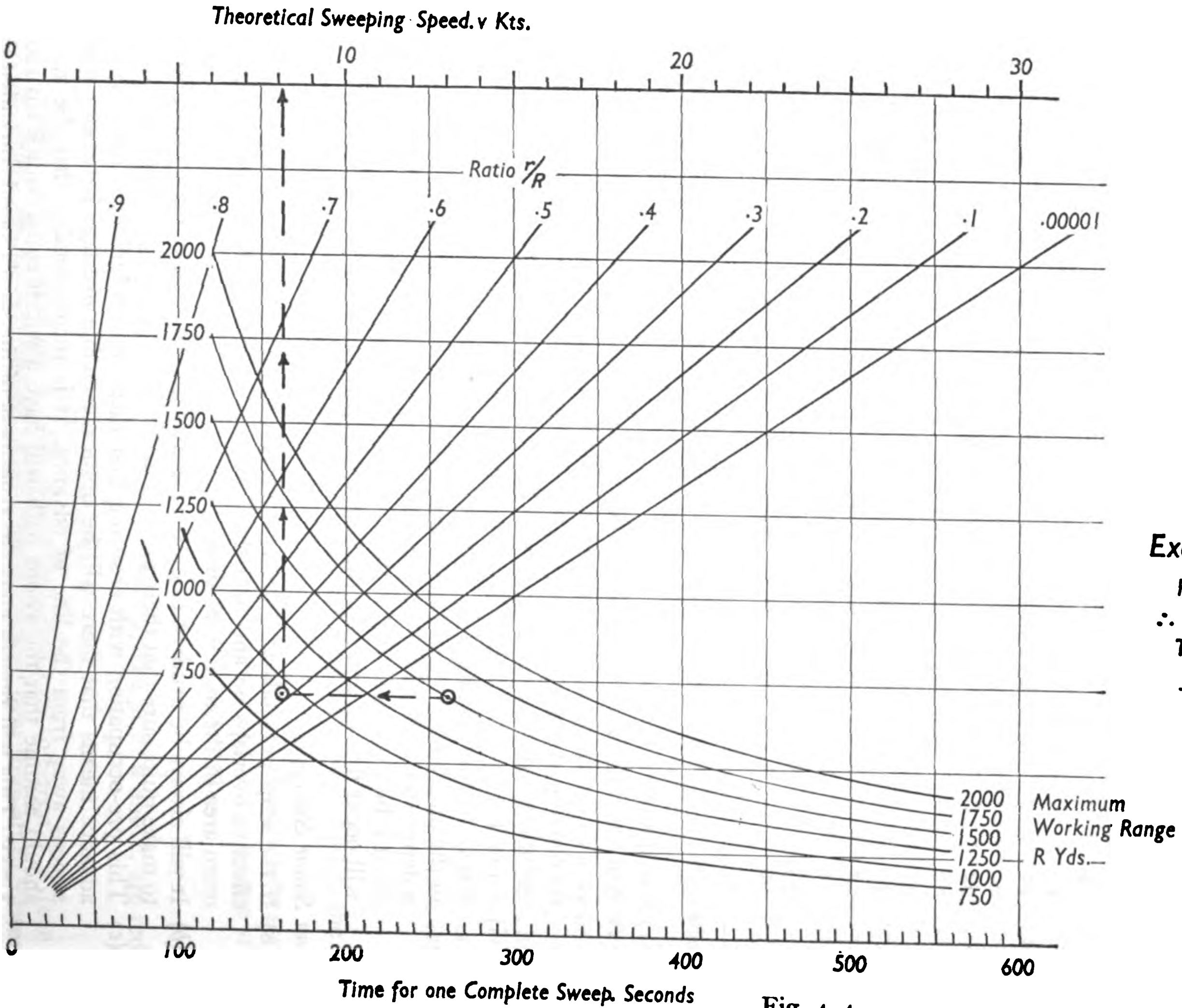
Notes on Sonar Sweeping

(*a*) If the ship proceeds at v knots made good, there will be no holidays and no effective overlaps on and near the line of advance, and she will cover the maximum area in the minimum time.

(*b*) It will always be prudent to proceed at a speed less than v (perhaps say at $0{\cdot}75v$) to make quite sure that there are reasonable overlaps along the line of advance.

(*c*) This pre-occupation with ensuring that there are no holidays along the line of advance means that there will be quite reasonable overlaps between successive sweeps away from the line of advance. It is recommended that the surveyor should assume that the swept path will have a width equal to $2(R \sin 120^\circ) = 1{\cdot}73R$. This will remain constant regardless of the ship's speed, provided this is

Sonar Sweeping Diagram



Example (See Pecked Lines)

R = 1500 Yds. r = 356 Yds.

∴ r/R = 0·237

Time for one Sweep = 260 secs.

∴ v = 8·1 Kts.

Fig. 4–4

not greater than v, and regardless of the time taken to complete one sweep. Since the maximum width of the swept path can in no circumstances exceed $2R$ this cautious policy will have little effect on output.

(*d*) Overlaps between adjacent swept lanes must be chosen using common sense. If lines are run 1·73 R apart, there will in theory be small overlaps between swept lanes even when the ratio r/R is very small, and v therefore comparatively great. In practice it might well be prudent to run lines about 1·5 R apart. Each case must be decided on its merits; the scale of the survey and accuracy of control must of course be taken into account.

(*e*) The surveyor must not spend too long classifying contacts, or the whole purpose of the search sweep will be frustrated. On no account should the sonar be allowed to hang around on an echo forward of the beam. Contacts which are not 'disregarded' should be closely examined later on as a separate operation.

(*f*) All the notes above assume that the sonar beam behaves itself properly, travelling in straight lines to its maximum working range R. The surveyor at sea must always make sure that his set is working properly, and use his judgement and experience in selecting prudent values for the variables on which his speed made good will depend; he must apply the same judgement and experience in selecting the spacing between his lines of sweep.

(*g*) If large alterations of course are made whilst sweeping, great care must be taken not to leave gaps on the outside of the bend. It may well be prudent to leave the sonar trained on the outer beam, and let a gradual alteration of ship's head sweep it round; the inside of the bend will usually look after itself if this is done.

(*h*) Systematic sonar sweeps for normal surveys should aim to cover the whole area in two directions at right angles to each other. It will almost always be better to do this than, for instance, to run lines closer together in one direction, particularly when there are sand waves in the area. In very special cases it may be prudent to run the lines in two directions at right angles to each other, and space them about 1·0R apart. This should ensure that every part of the sea bed is looked at from at least four different directions.

c. Types of sonar contact which may be found by the surveyor

The surveyor is interested only in the types of contact which the anti-submarine specialist classifies as being 'non-sub'. These contacts will generally fall into one of the following classes:

(i) They may be wrecks, or pinnacle rocks or coral knobs, rising abruptly from the bottom.

(ii) They may be caused by the configuration of the sea bed.

(iii) They may be caused by something in the water, lying between the sea bed and the surface.

(i) Wrecks, pinnacle rocks and coral knobs. Wrecks usually, but not always, give a well defined echo of small extent, which may be easily distinguished from reverberations and background noise. The echo amplitude may well vary with bearing; it will very often be possible to hear an echo long before it possesses sufficient strength to mark the sonar recording paper. In a tideway it is very probable that the amplitude of a wreck echo will vary as the tidal stream changes; water eddies set up around a wreck can also mask the true nature of its echo, making it more 'woolly' than it should be. It should never be forgotten that a wreck may well lie at the bottom of a deep scour, and therefore be 'invisible' to the sonar beam from certain directions.

Pinnacle rocks can give echoes which are very wreck-like in their nature. Sometimes they can be distinguished from wrecks only by considering the general nature of the sea bed. If there is any doubt they should be examined as thoroughly as a potential wreck. A diver will of course resolve any doubts as to their true nature.

Sonar echoes from coral knobs are usually very strong and resonant compared with those from similar sized wrecks or rocks. This is probably due to their cellular structure, and to the myriads of fish which usually inhabit them.

(ii) Sea bed echoes. Echoes from the sea bed can nearly always be identified from their comparatively large extent, either in range, or bearing, or both. A gently shelving bank, viewed broadside on, will generally produce a ripple effect. The steep face of a sandwave will often produce a hard and resonant echo, but it will have too great an extent in bearing to be a possible wreck. The sonar recorder trace is often a great help in identifying and interpreting sea bed echoes. The surveyor may also, of course, refer to his sounding tracing, which will give him a good idea of the general configuration of the sea bed before he starts to sweep.

(iii) Water echoes, fish, floating objects. Fresh water springs. It should never be forgotten that sonar echoes may be obtained from things in the water, or even the water itself, as well as from things lying on the bottom.

Fish are excellent reflectors of the sonar beam. A single target, such as a whale, can give an echo very like that of a submarine; it may or may not produce a doppler shift; it will usually be moving. Shoals of fish may produce wreck-like echoes or ones which have too large an extent to be a wreck. It should not be thought that fish echoes should always move; quite often shoals of fish remain in the same place for some time, even in a tideway. Very often a close investigation subsequent to the main sonar sweep is the only way to establish their true nature.

Buoyant objects tethered to the sea bed can float below the surface, as well as on it; and in these circumstances they can give echoes which are virtually indistinguishable from those of wrecks. In one instance a surveying vessel discovered two 'wrecks' lying close together, with sonar. The first, and major wreck, responded well to subsequent wire sweeping operations. The second, smaller 'wreck', although apparently dangerous to navigation, refused to respond to treatment; the least depth over it seemed to vary from hour to hour. It was only after some time that the truth dawned; an oropesa sweep, set to run fairly deep, cut loose a spherical buoy which had been abandoned some twenty feet below the surface during wreck dispersal operations.

Fresh water springs, issuing from the sea bed, can give hard and resonant echoes indistinguishable from those from coral knobs, rocks and wrecks. Or they can give echoes which are less well defined, and more like those from a school of fish. They are probably the most difficult things which the surveyor will want to identify with his sonar set. The simplest certain way to establish the identity of a fresh water spring is to sweep right through it with oropesa gear, and take a sample of water over it; the salinity will be very much less than that of a sample obtained a cable or so away if it is a spring, and the oropesa will establish a least safe depth of water. In some areas of the world, such as parts of the Persian Gulf, fresh water springs are so numerous that vast areas would have to be swept with a wire sweep to establish a certainty that no dangers existed. In such circumstances the prudent surveyor might well establish positively the nature of one or two springs, and then rely on his experience and his sonar set to find the others. Where reasonably large fresh water springs exist they will always show up on an echo sounder trace, and their rough positions should therefore be known before the sonar sweeping starts.

d. Fixing a wreck accurately with sonar

For various reasons the position of a wreck obtained from a sonar sweeping plot (which has probably been carried out on a fairly small scale) is not likely to have an accuracy much better than about ±200 feet. This is usually quite good enough for the mariner, since the wreck symbol on a chart will generally be much larger than this when the scale is taken into account. However, it may not be good enough for the surveyor, who wants to carry out wire sweeping operations.

He may well be tempted to take his vessel directly over the wreck, adjusting his course as necessary to keep the sonar bearing constant, and then switching on the echo sounder at the last moment in order to obtain a fix as the wreck appears on the echo trace. He must resist such a temptation at all costs, unless he is absolutely certain that there is more than sufficient water over the wreck for him to do so. If he does not, then sooner or later he will find the least water over a so-called safe wreck with the sonar dome of his vessel.

Most sonar sets provide ranges far more accurately than bearings. A wreck may therefore be fixed by three or more sonar ranges taken into it from known positions, perhaps a cable or two away. If an electronic fixing device is being used, the ship may steam in turn along a convenient lane in each pattern, and record the minimum range into the wreck in each case; this will enable the co-ordinates of the wreck to be computed. Sideways looking sonar can be of great use in fixing wrecks accurately without sailing right over them.

In the last resort, and where all else fails, a boat must be lowered to locate and fix the wreck, whilst the ship waits at a safe distance.

e. Sonar sweeping records

Records may be divided into two classes; those kept in the field as the work proceeds, and those which are forwarded into office for permanent custody.

(i) Field records. A separate sounding board should always be used for sonar sweeping. Fixes should be inked in on the completion of each day's work; they will look something like those shown on Fig. 4–5. The various sonar contacts should be left in pencil until their nature has been identified with certainty; they may then be inked in. Manuscript notes may, of course, be used liberally on the sounding board. The examination of contacts must continue until each has been positively classified; ephemeral contacts, such as those caused by fish and water eddies, should be expunged as soon as the surveyor is satisfied that they are in fact ephemeral. Before the field work can be considered to be complete every contact shown on the board must be classified as belonging to one of the permanent features listed in **c** above.

The sonar deck book must contain a record of all the fixes, and the various sonar ranges and bearings. It must also contain a note of the maximum working range R, the minimum detection range r, the ratio r/R, the time taken for one complete sweep, the speed made good v, the actual speed through the water and made good, the distance apart of the sweeping lines, and the angular steps in which the sweep is being carried out. These things should be noted at the beginning of each day's work, and whenever any of them change during the day.

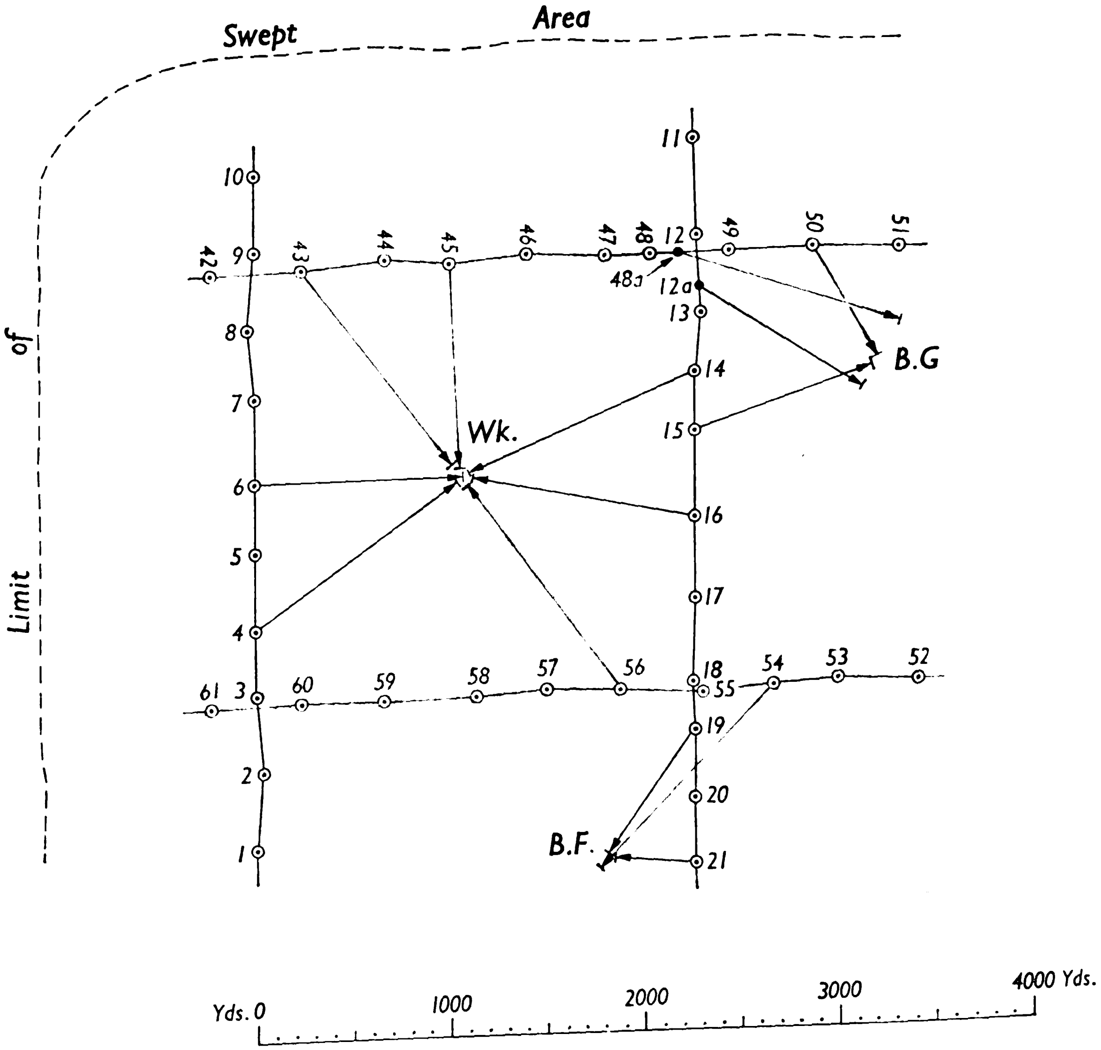
During a search sweep the sonar should never be held up unduly on a target, whilst a fix is obtained. The ship's position can always be stepped back from the next fix, using a corrected log distance or by timing. Intermediate 'fixes' of this type are shown on Fig. 4–5 between fixes 12 and 13 and 48 and 49.

(ii) Permanent records. The main permanent record is the sonar sweep fair tracing. Part of a typical tracing is shown in Fig. 4–5. It must show:

(*a*) The limits of the area swept.

(*b*) The ship's track, with fixes. The two sets of tracks at right angles to each other can be differentiated by using different colours.

(*c*) All permanent contacts. These should be indicated by an arrow, whose tail starts from the relevant fix, and whose head has a short bar across it, indicating



Natural Scale 1/36,000 Approx.

Fig. 4-5

the detection range. The arrows should be drawn in the same colour as the fixes from which they originate.

Positive classification of all contacts shown should be given, either in manuscript or in code, the key to which must appear on the tracing. The following code can be recommended:

Wk = Wreck
G = Good contact
F = Fair contact
B = Bottom or bank echo
S = Fresh water spring
U = Unexamined.

Figure 4–5 shows one wreck, and two bottom or bank echoes, one of which is good, and the other fair.

The code letters G and F should be used descriptively, to amplify the positive classification of a target; used by themselves they will be valueless.

Only in exceptional circumstances should a contact appear as unexamined. In such cases the report of survey must always explain the reason.

Ephemeral contacts should not appear on the tracing. The surveyor must always continue his investigations until he can make definite decisions as to the existence of wrecks, bottom echoes, or echoes caused by fresh water springs or other permanent phenomena in the water itself.

If an area is congested with many contacts a system of numbered references may be used; it should be related to a memoir or to a separate list, which should accompany report of survey.

As with all permanent records the surveyor should, if anything, err by including too much information on the sonar sweep fair tracing, and in his report of survey, rather than too little.

4. Sideways looking Sonar

Sideways looking sonar was originally developed to assist anti-submarine vessels to identify bottomed submarines. It has since been used by geologists and surveyors to examine all kinds of bottom features. The present state of development limits its use to assistance in classifying bottom echoes, once these have been discovered by the traditional sonar sweep described in Sections 2 and 3 above; it will not do the job of the main sonar set. However, there are hopes that with continued development a sideways looking sonar may emerge which will enable the surveyor to detect and identify sonar targets which lie between his normal lines of sounding, and to do this whilst he is actually sounding.

a. Sideways looking sonar. Basic principles

In Fig. 4–6 the ship is fitted with two special transducers which are energised together by a fairly powerful transmitter very similar to that used in a typical echo sounder. A recorder, again very similar to those used in ordinary echo sounders, controls the transmission cycle, and records any 'echoes' on sensitised paper. The maximum range of the recorder is generally about 600 yards (300 fathoms); this range is accommodated on the width of the sensitised paper, and there are no phasing arrangements.

One of the transducers transmits vertically downwards; the other transmits on the beam. Both are designed so that their beams will have a large extent in the vertical plane, and be very narrow in the horizontal plane. When they transmit together they 'illuminate' a narrow wedge of water on the beam of and under the vessel, from the surface of the sea to just beyond a point vertically below the ship. In the figure the various segments of circles represent the transmission pulses proceeding outwards from the vessel. The strip at the bottom of the figure is a greatly enlarged representation of one trace of the recorder stylus.

Imagine that a pulse of energy is just being transmitted by the two transducers. The transmission line will be recorded on the trace in the usual way. The energy will proceed downwards and outwards in a narrow vertical wedge. The first echo will be received from the bottom at *A*, and will mark the trace in the same way as it does in an echo sounder. As the pulse proceeds outwards continuous bottom echoes will be received from the sea bed between *A* and *B'*. These echoes, which are analagous to the reverberations in a normal sonar set, will become weaker as the range increases; the gain of the set is adjusted (very often by increasing it automatically with increasing range) so that they darken the trace nicely and fairly evenly out to the maximum range.

Now consider what happens when the echo arrives back from *B'*. At this instant an

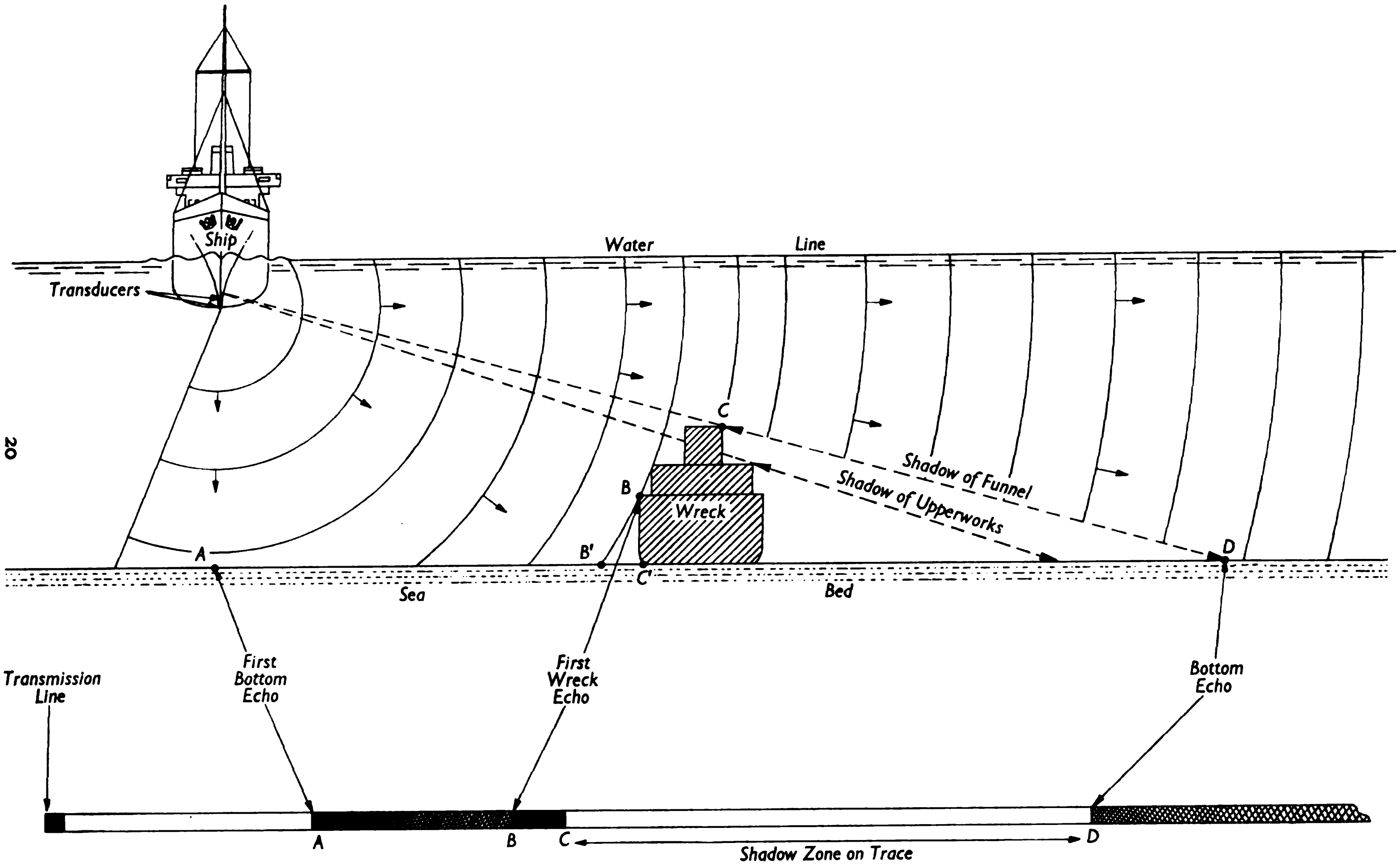

Ship
Water
Line
Transducers
C
B
Wreck
Shadow of Funnel
Shadow of Upperworks
A
B'
C'
D
Sea
Bed
Transmission Line
First Bottom Echo
First Wreck Echo
Bottom Echo
A
B
C
D
Shadow Zone on Trace

Fig. 4–6

echo will also be received from the nearest part of the wreck at *B*; the intensity of the trace will therefore suddenly increase. Bottom echoes and wreck echoes will be arriving together from all points between *B′B* and *C′C*. The equivalent part of the trace, *BC*, will therefore be very dark. Beyond *C* the funnel of the wreck casts a shadow, and no echoes can be received from the area between *C* and *D*, unless they come from something in the water above the shadow zone. The part of the trace between *C* and *D* will in theory therefore be unmarked; in practice a few scattered marks may perhaps appear. At *D* the bottom is picked up once again, and marks the trace in the usual way.

Note that the funnel casts a longer shadow than the upperworks, and that these shadows will appear light on the echo trace, not dark. Note, too, that some of the energy may well pass either side of a fairly thin structure such as a funnel or a mast, so that their shadows may well be less ‘dense’ than those cast by larger structures.

Figure 4–7 shows the trace produced by a typical sideways looking sonar in perfect adjustment, and operating under ideal conditions. The shadow of a wreck lying nearly

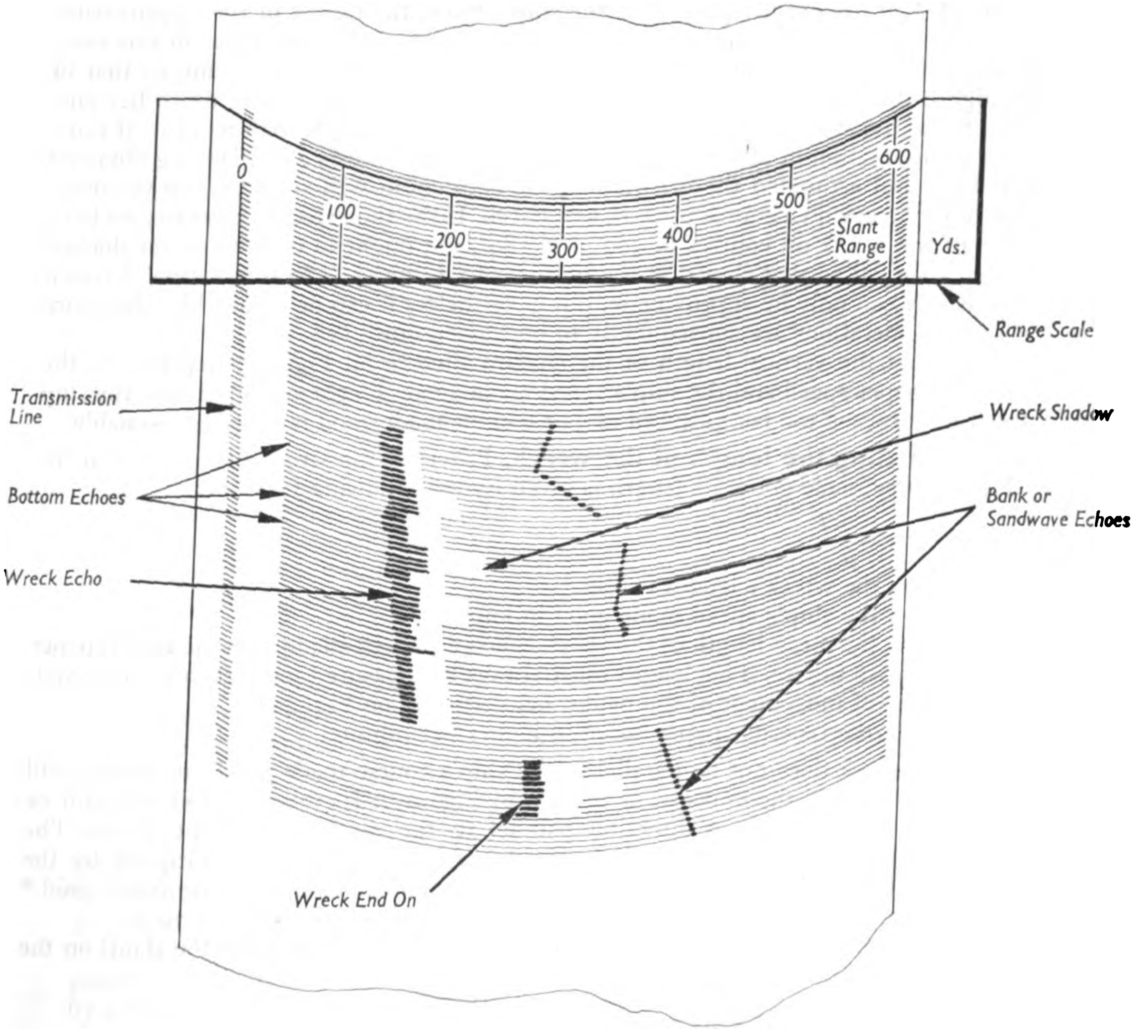


Fig. 4–7

parallel with the ship's course made good may be seen, as well of one from a wreck which is lying end on. The small echoes lying beyond these wrecks are typical of those received from bank or sand-waves. These features usually strengthen the trace sufficiently to stand out plainly; they may or may not cast shadows, depending on their height, slope and range; in this particular case they do not.

Most sideways looking sonars have three transducers; the equipment may be made to look on either beam, by switching the port or starboard transducers into parallel with the bottom unit. There is no reason in theory why a set should not be made to look on both sides at the same time.

b. Sideways looking sonar; interpreting the trace

The relationship between the characteristics of a wreck lying on the sea bed and those of its shadow picture on the trace may be determined by the methods set out below.

(i) Orientation of the wreck. If the wreck lies more or less parallel with the ship's course made good, a shadow picture similar to the large one on Fig. 4–7 will be obtained. If it lies exactly parallel to the ship's track, the ranges of the various parts of the dark echo will remain constant as the ship passes along it. If, as in this case, it does not lie quite parallel, these ranges will vary. Suppose, for example, that in the figure the ship's course made good is 090°; the wreck is passing down her port side. Since the wreck's stern (top) is closer to the ship's track than its bow, it must have an orientation of about 280°–100°, with its bow towards 280°. Having obtained this trace and estimated the orientation, the ship could well steer to pass the other side of the wreck on a course of 270°, as a check. If she then steered so as to pass both sides of the wreck on courses of 360° and 180°, she ought to obtain end-on shadow pictures similar to that shown at the bottom of the figure. The orientation obtained in this way can only be approximate, but nevertheless it can be invaluable when wire sweeping operations are subsequently to be carried out.

Note that the vertical length of the shadow picture on Fig. 4–7 depends on the recorder paper speed and the ship's speed made good. To get a good picture the ship must not proceed too fast; a speed of 5 or 6 knots made good is usually reasonable.

(ii) Estimating the length of the wreck. Provided the wreck lies parallel to the ship's course made good, its length is given by the following formula:

$$L = \frac{100vl}{p}$$

where L = the wreck's length in feet,

v = the ship's speed made good in knots,

l = the mean length of the wreck echo and wreck shadow on the record paper in inches. This length must always be measured parallel to the direction of movement of the paper, i.e. vertically on Fig. 4–7,

and p = the recorder paper speed in inches per minute.

If the wreck does not lie parallel to the ship's course made good, its shadow will lie at an angle to the vertical, as it does in Fig. 4–7. In this case l should still be measured in inches in a direction parallel to the movement of the paper. The apparent value of L obtained from the formula must then be multiplied by the secant of the angle between the wreck's heading and the ship's course made good.* In the example quoted in (i) above this angle would be 100°–090° = 10°.

On no account should the length of the wreck be measured 'on the slant' on the record paper, since the scales in the horizontal and vertical directions on the paper are very different.

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* The correction is 6% if the angle is 20°, and 41% if it is 45°; the apparent value of L will always be smaller than it should be.

It is recommended that when measuring the length of a wreck in this way the surveyor should always adjust his course so that the wreck echo and shadow would in fact lie vertically on the record paper in Fig. 4–7.

(iii) Estimating the height of the wreck. In Fig. 4–8, the ship is investigating the wreck with sideways looking sonar, and wishes to obtain its height h above the sea bed. The following measurements can be obtained from the trace:

a, The slant range to the (black) echo on the trace.
s, The slant range to the far edge of the (white) shadow.

The distance d, between the transponders and the sea bed can either be obtained from the sideways sonar trace, or better still from an echo sounder. Note that this distance is not the depth of water; the transponders draught must be allowed for.

Referring to the figure,

$$h = (s-a)\sin\theta,$$

and

$$\sin\theta = d/s.$$

therefore

$$h = \frac{d\,(s-a)}{s}.$$

The calculation may be made in any units, but they must all be the same. Note that most sideways looking sonars present a, s and d in yards.

If, as will generally happen, the black echo on the trace has appreciable width, it will be difficult to determine to just what part of it the slant range should be measured. It will generally be safest to measure to the centre of the echo. If the leading edge is taken the resulting height will probably be greater than it ought to be; conversely use of the trailing edge will probably produce heights which are too small.

There should not be the same difficulty in measuring s, since the far edge of the (white) shadow is usually well defined.

(iv) Estimating the list of the wreck. Some idea as to whether a wreck lies on an even keel or has a list can be obtained by running up both sides of it on courses parallel to its heading, and at equal ranges. If the wreck lies on an even keel the shadow picture obtained from both sides will be the same. If it has an appreciable list, the shadow picture from one side will show its upperworks (if it has any), whilst that from the other will not.

This method is not infallible, and it will not work at all unless the wreck has some features sticking out above its main box-like structure.

c. Limitations of sideways looking sonar

Since a wreck shadow cannot be produced unless the set is receiving bottom echoes strong enough to darken the trace appreciably, the performance of a sideways looking sonar must depend on the depth of water, the quality of the bottom, and the water conditions.

Experience indicates that provided the reflecting qualities of the bottom are reasonable and the water conditions are fairly good, the bottom echo will darken the trace nicely out to slant ranges between six and seven times the depth of water. Thus in 20 fathoms the working range of the equipment could be expected to be just under 250 yards; in 40 fathoms it would be double this amount.

If a wreck lies very close to the ship's track, its shadow will be very small; if the ship passes immediately over it the trace will of course be exactly similar to that produced by a normal echo sounder. In theory there is no danger of missing an object which lies close to the ship's track. In practice there will be a slight risk, particularly if the object is small; this risk is a natural consequence of the fact that the intervals between the

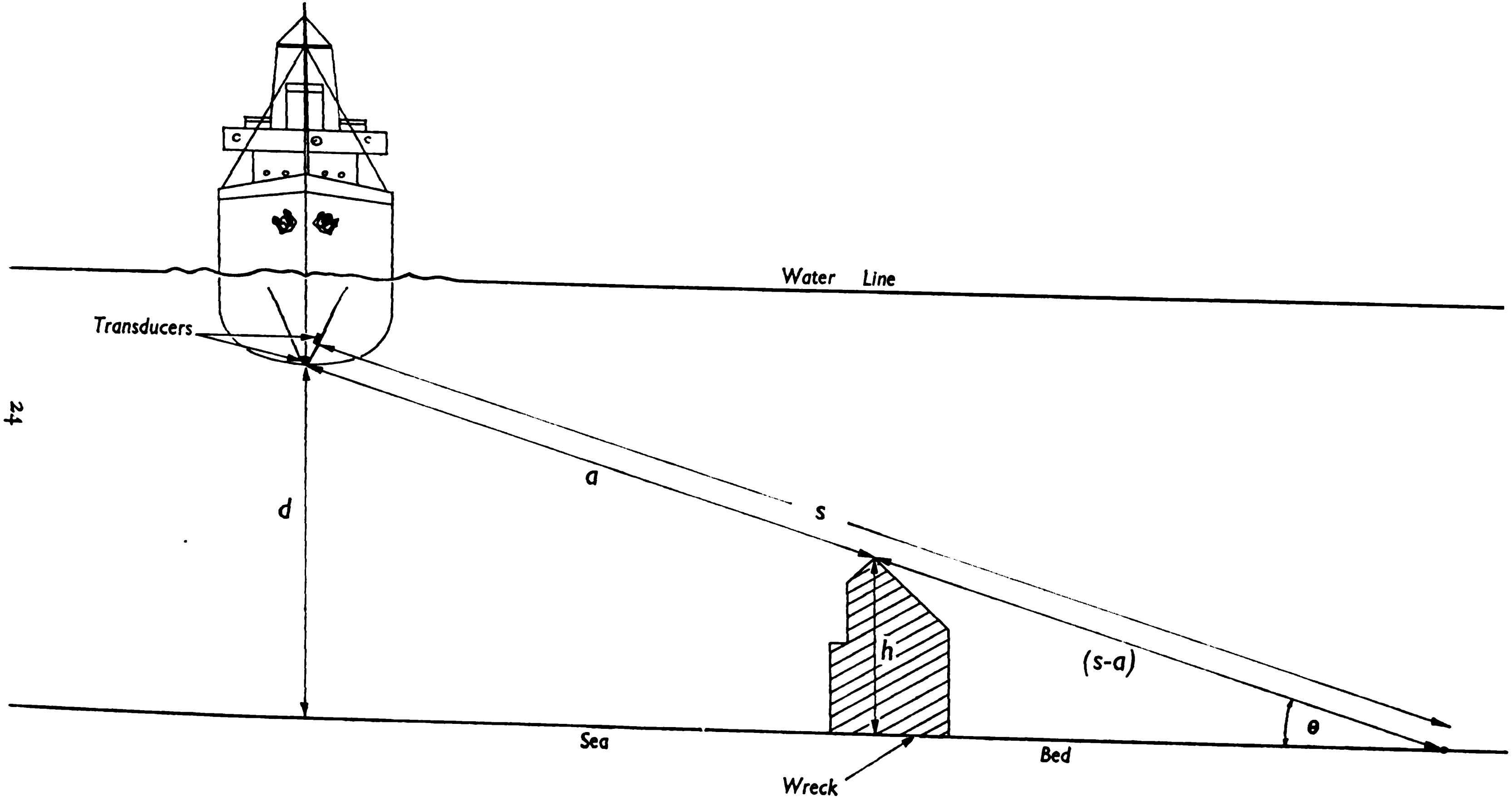


Fig. 4–8

transmissions of a sideways looking sonar must be fairly long, in order to obtain the ranges required. Thus an object lying close to the ship's track may be illuminated by only a few transmissions before it passes out of the beam, and the resulting echo and shadow may not be noticed on the trace.

The descriptions and procedures set out in **a** and **b** above assumed that the equipment is being used in ideal conditions. For instance, in Fig. 4–6 it is assumed that the various echoes arrive back at the ship by the shortest direct paths only. In practice these echoes can also return via many other paths, perhaps involving multiple reflections; the situation can be confused still more by multiple reflections between the ship's hull and the target. All these things will tend to make the average shadow picture obtained in practice much less well defined than those shown on Fig. 4–7. The surveyor using sideways sonar must, as always, use his experience and judgement in interpreting the trace.

At the present time (1968) sideways looking sonar cannot be used to replace the main sonar sweep which must generally be carried out once the sounding is complete. It would be a very attractive proposition if it could be operated whilst a ship was sounding, and if the surveyor could rely upon it to detect and identify all objects, both natural and man-made, which broke up the smooth contours of the sea bed between his lines of soundings. At the present time a typical sideways sonar operated in this fashion usually detects so many apparent objects, both large and small, that it leaves the situation more confounded than before. Additional research, and the use of electronics, and perhaps even of computers, with the aim of making a complicated trace more intelligible, may well result in a satisfactory 'search and identify' set being produced in the next few years.

Part 2 Oropesa Sweeping

5. The WS Mark IV Oropesa Sweep

The WS Mark IV oropesa sweep is a single ship sweep suitable for use at speeds up to about 12 knots. It was originally designed for mine clearing. For surveying purposes it has been modified in some ways, and has been extremely valuable both for locating wrecks and shoal patches (in the days before sonar was in general use) and for clearing areas to a certain depth.

Figure 4–9 shows plan and elevation views of a vessel towing a double oropesa sweep. The two sweep wires are pulled out on their respective quarters by the otters, which are held at the correct depth by the floats. At the ship end both wires are held down at this same depth by the kite. Kite and otters are identical, and are made to carry out their different functions by fitting them with different slings. The unsupported bights of sweep wire between kite and otters will tend to sag. This tendency is counteracted by using right hand laid rope for the starboard wire, and left hand laid rope for the port wire; as the wires move through the water an upward thrust is developed on the lay of the wires, which tends to counterbalance the sag.

The spread of the sweep (i.e. the distance between the two otters) depends on the design of the otters, the speed of the ship, and the amount of sweep wire veered. The depth keeping qualities of the sweep have never been investigated really thoroughly, but are probably about ±1 fathom. The sweep must not be run too near to the bottom, or the kite and otters, which all run below the level of the wire, may strike the sea bed; if possible at least two fathoms clearance should be allowed; if the wire is set to run as close to the bottom as one fathom, the kite will very probably foul from time to time.

In theory the double sweep shown in the figure is very attractive. However, it is unhandy to use, and it will generally be more prudent to use a single sweep set on one side or the other, and make the best use of the tidal stream. For a given speed the spread of the sweep (single or double) does not increase linearly with the amount of sweep wire veered. As more wire is paid out the drag increases, and there will come a time when the float merely drops further astern, without going any further out from the ship's track. A reasonably compact sweep, run at the correct speed, will always be easier to use and will generally cover more ground in a given time than a very long and unwieldy sweep.

a. Components of the sweep

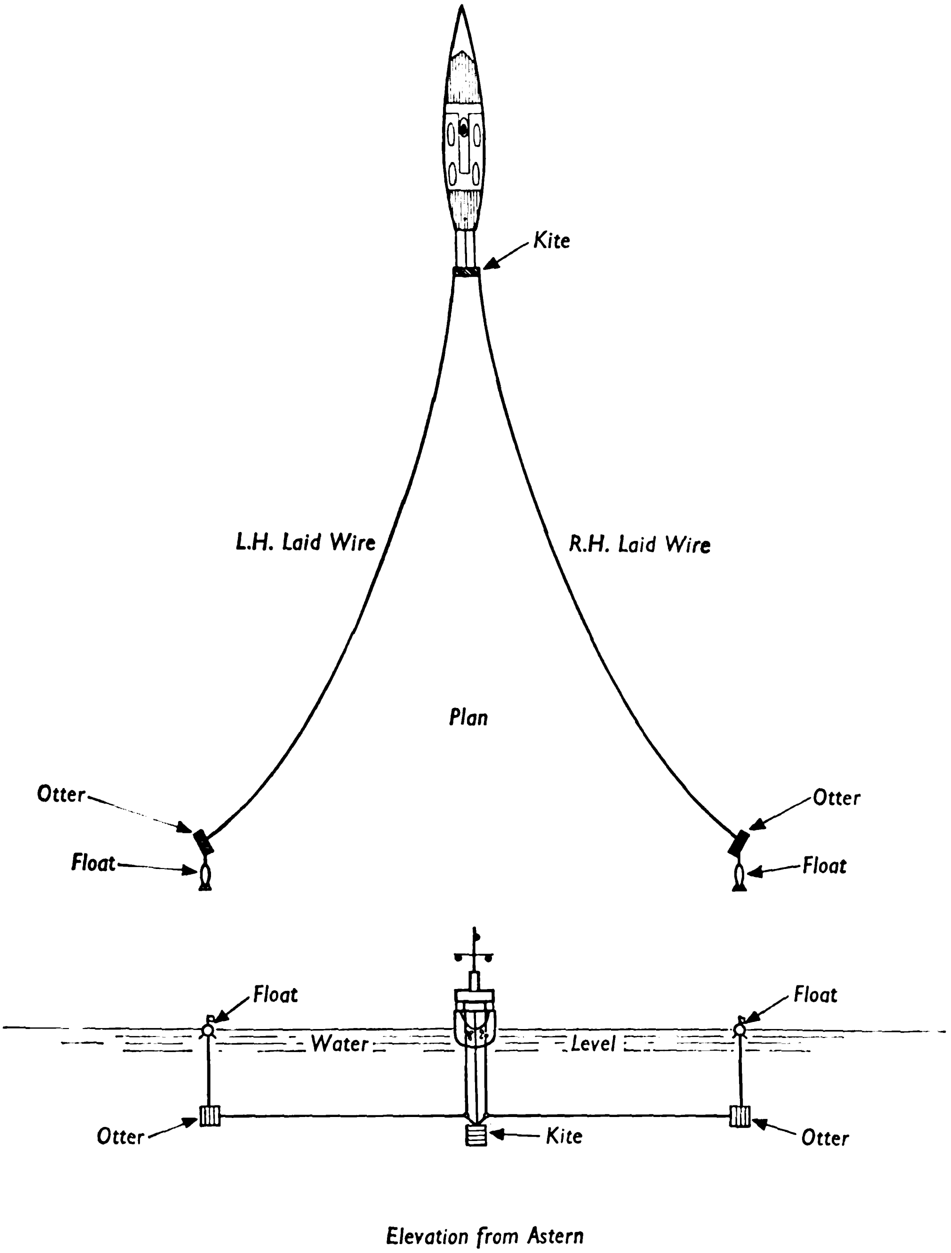
The principle items needed to make up a double sweep are:

(i) *Three kite/otter multiplanes*

These are rectangular steel box frames fitted with vanes. Two are used as otters for pulling the sweep out on either quarter; the third is used as a kite for keeping the ship end of the sweep down. The construction of all three is identical, though their slinging arrangements differ, as shown in Fig. 4–10.

(ii) *Two sweep wires*

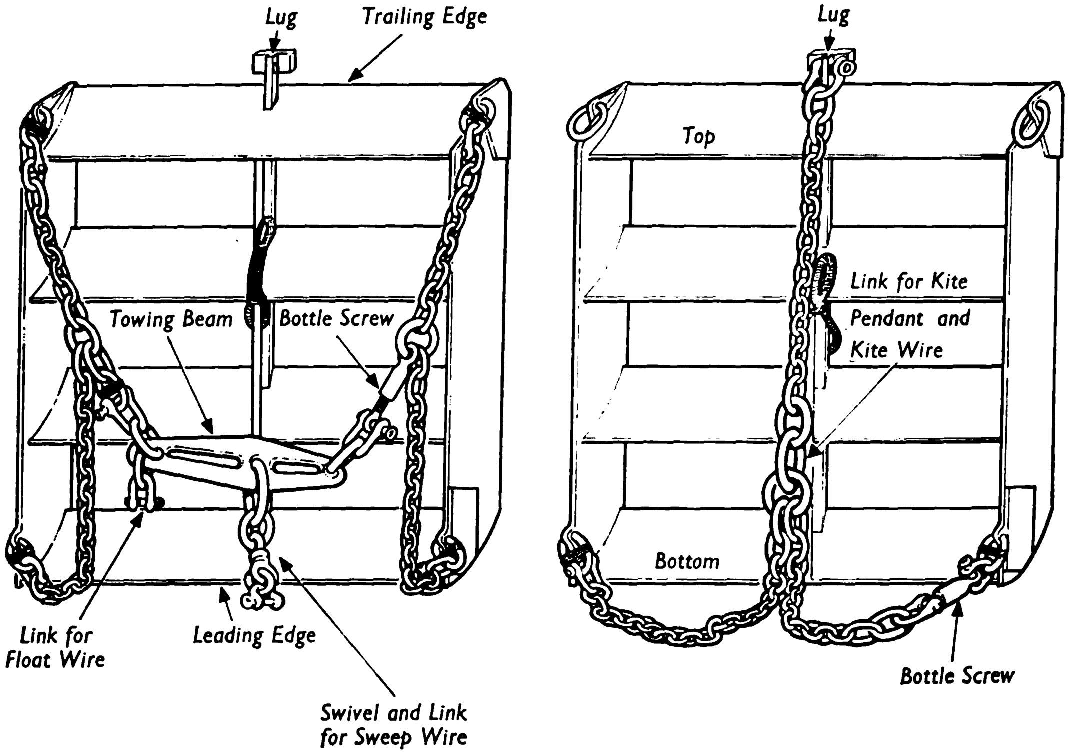
Each consists of 450 fathoms of 1¼ inch British mine-mooring wire, one right hand laid for use on the starboard quarter and one left hand laid for use on the port quarter. It is usual to mark them with paint every 50 fathoms. Soft eyes are worked into their outer ends, using Bulldog grips.



Double Oropesa Sweep

Fig. 4–9

KITE/OTTER MULTIPLANE



Slung as a Starboard Otter

Slung as a Kite

Fig. 4–10

(iii) *One kite wire*

This is made from 1¾ inch extra special flexible steel wire rope;* it should be about 100 fathoms long, and marked in a similar manner to a lead line at every fathom between 5 and about 65 fathoms from its outboard end. A thimble eye, to take the kite slings, should be worked into its outer end. The kite wire must always be shackled to the ring of the kite slings forward of the kite pendant.

(iv) *Two floats*

These support the otters, as indicated in Fig. 4–11. Each float carries a small flag, so that it can be seen easily.

(v) *Float wires*

The float wires connect the floats to the otters, and are made from 1¾ inch flexible steel wire rope.* It is usual to make them of various lengths, which may then be shackled together to make any total length required, to the nearest half fathom. Each complete float wire is shackled directly to the towing beam of its otter, and connected to its float via a swivel and slip (see Fig. 4–11).

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* The sizes are important, since the validity of the kite and float wire tables depends on them.

(vi) *Two kite pendants and snatch blocks*

These connect the kite to the sweep wires (see Fig. 4–11). The kite pendants are made from 1¾ inch flexible steel wire rope. By tradition they are 5 feet long.* It is important that these lengths should be adhered to, since if they are not the relationship between the amount of kite wire veered and the depth of the ship end of the sweep will be incorrect. If, for any reason, kite pendants longer than five feet must be used, then the surveyor should determine for himself the relationship between the amount of kite wire veered and the depth of the sweep at its inboard end. If two kite pendants are used (double oropesa), they must be shackled together and then connected to the ring of the kite slings with one shackle. On no account should they be shackled separately to the kite slings.

(vii) *Two four-legged chain slings*

These are fitted on a beam, with a bottle screw adjustment, and connect the otters to the sweep wires. (See Fig. 4–11.) The way in which the slings are attached to a starboard otter is shown in Fig. 4–10. Note that the longer legs are attached to the leading edge of the otter, and that when it is running the bottle screw will be below the beam. If the otter is to run to port then the towing beam must be turned end for end, so that the bottle screw will again be below it when the otter is running, and the chain legs must be unshackled, turned over and shackled on again so that the longer legs can once more be attached to the leading edge. It is good practice to mouse the end links which are attached to the otter with seizing wire, to prevent them tumbling accidentally. There must be no turns in the various chain legs, and all shackles must be well moused.

(viii) *One three-legged chain sling*

This connects the kite to the kite wire and kite pendant. (See Figs. 4–10 and 4–11.) Note that the bottle screw is always in the port lower leg. The various legs must be free from turns, and all shackles must be well moused.

(ix) *A winch or winches*

Winch facilities that will handle both sweep wires and the kite wire simultaneously are required. If necessary the kite wire may be handled round a capstan. The most convenient layout consists of a minesweeping winch with independently driven barrels for the sweep and kite wires, and warping drums at either end.

(x) *Deck fittings*

Three roller fairleads are needed, one for each sweep wire, and one for the kite wire. They should be fitted as close together as possible. It is usual to have two special sweeping davits on which the kites, otters and floats may be hoisted in and out.

b. How the sweep works

Figure 4–11 shows a starboard sweep running at short stay. The kite pulls the ship end of the sweep wire down to a depth which will depend on the amount of kite wire

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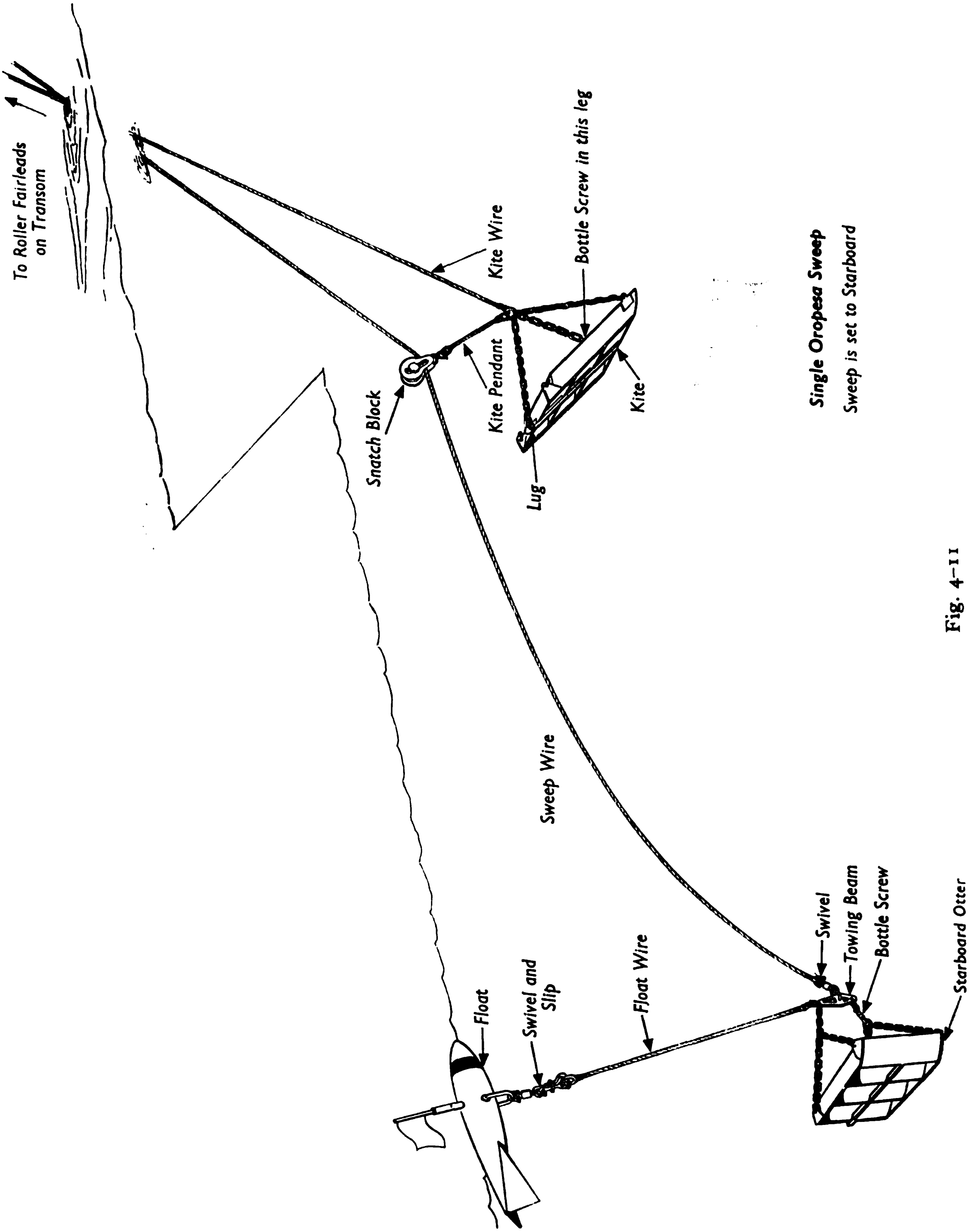
* Although there is no certain evidence of the fact, it seems likely that this length was originally chosen so that the complete kite pendant snatch block assembly would be one fathom long.



Single Oropesa Sweep

Sweep is set to Starboard

Fig. 4-11

veered, the speed of the ship, and the length of the kite pendant. The bottle screw in the port lower leg of the kite must be adjusted until the kite runs truly dead astern of the ship; if this adjustment is not carried out properly the kite will tend to yaw about, and may even perhaps break the surface, with disastrous results.

The otter pulls the sweep out on the quarter, and its lateral distance from the ship's track through the water will depend on the speed of the ship and the amount of sweep wire veered. Its tendency to dive may be controlled with the bottle screw fitted in the lower legs of its slings. This screw must be adjusted until the float behaves in the correct manner. The depth of the outer end of the sweep wire will then depend mostly on the length of the float wire, and to a lesser degree on the speed of the ship.

Between the kite and the otter the weight of the sweep wire will tend to make it sag, and the action of the water on the lay of the rope will counteract this effect. For any given length of sweep wire a certain ship's speed will produce a relatively flat sweep. However, it is important to note that no sweep wire can ever be quite flat along its entire length; the shorter it is the more nearly flat will it become at the correct speed.

6. Preparation of Oropesa Sweep gear for running

Before an oropesa sweep can be run properly, certain adjustments must be made to the kite and otters and their respective wires and associated fittings. These adjustments may be made at any convenient time, and once made are not likely to need altering unless the sweep suffers physical damage.

a. Adjusting the kite

Before a kite is used it must be adjusted so that it runs truly. The process is as follows:

(i) Attach the kite to its slings in the way shown in Fig. 4–10. The bottle screw should be in its middle position. Take great care that there are no turns in any of the legs, and mouse all shackles thoroughly.

(ii) Reeve the kite wire through its fairlead on the transom, bring its end inboard again, and shackle it to the correct link on the kite slings.

(iii) Hoist the kite outboard on the davit, and lower it until it is hanging against the transom with its weight on the kite wire. If a stream anchor is fitted it will be prudent to remove it, so that it cannot foul the kite or its wire.

(iv) Reduce speed to about two knots. Veer the kite wire under power.* As soon as the kite reaches the water it should 'bite', and will pull downwards and astern. Veer until the five fathom mark on the kite wire is awash.

(v) Increase speed gently up to about six knots. The kite should tow dead astern, quite steadily, and the kite wire should leave the roller fairlead at an angle of about 40° below the horizontal.

(vi) If all is well increase speed gradually until the maximum sweeping speed is reached. If all is still well veer the kite wire in steps to at least 20 or 30 fathoms. The adjustments become more critical as the speed increases and as the kite wire is veered.

(vii) In most cases the kite will not run true to start with. It must then be recovered and the bottle screw in the port leg adjusted as follows:

If the kite sheers to port, lengthen the bottle screw; if it sheers to starboard, shorten the bottle screw. Make a bold adjustment to start with, and until the error has been over-corrected. As a rough rule the number of whole turns to be taken in or let out on the bottle screw is equal to the difference in knots between the speed at which the kite starts to sheer and the maximum speed at which it is to be run.

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* If the wire is handled on a capstan, great care must be taken not to allow riding turns to form.

(viii) Do not be satisfied with the adjustment until the kite runs correctly at its maximum working depth and at maximum speed. Time spent here will be more than repaid when the sweep is run in earnest. Be very careful that the direction 'dead astern' is assessed correctly and do not be mislead by the tapering lines of the stern of the average vessel.

(ix) Once the adjustment is complete, mouse all the kite sling shackles very carefully indeed, and note the setting of the bottle screw. Stow the kite carefully in a place where neither it nor its slings can be damaged.

A properly balanced kite should run truly whether it be used in conjunction with a single sweep set to port or to starboard, or a double sweep. The outward pull of the sweep wire is automatically counterbalanced when the kite pendant is shackled to the kite slings aft of the kite wire.

b. Preparing the sweep wires, otters and floats

A new coil of sweep wire should be hung on a turn-table so that the whole coil can be turned as the wire is wound on to the sweeping winch drum. If an attempt is made to wind on directly from a coil which is lying on the deck, the wire will become hopelessly tangled. The wire should be led round the winch drum from the underside.

Before a new wire is used for sweeping it must be stretched and wound on to the winch drum much more tightly than is possible when it is fed on directly from the coil. This may be done in the following way, in at least 25 fathoms of water.

(i) Attach a set of four-legged slings to the otter in the way shown in Fig. 4–10.* Set the bottle screw to its middle position; the setting is not critical at this stage.

(ii) Pass the sweep wire through its fairlead, bring it back inboard and shackle it on to the swivel on the towing beam. Hoist out the otter and hang it from the fairlead on the sweep wire.

(iii) Attach a five fathom float wire to the float, hoist the float outboard and hang it on a slip hook from the davit. Shackle the free end of the float wire to the top of the otter's towing beam, making quite certain that it is clear and outboard of all fittings.

(iv) Reduce speed to about two knots and slip the float. It will tow astern from the otter. Make sure that the float wire is quite clear.

(v) Veer 30 to 40 fathoms of sweep wire at full speed, under power. The otter should ride well out on the quarter as soon as the winch is stopped. If it does not, slow right down and recover it, for something is wrong.

(vi) If all is well unclutch the winch drive, increase speed to six or eight knots, and veer the sweep wire on the brake until all but the last four turns have run out. Do not veer too fast. The otter must always be kept moving through the water, or the sweep will sag and may foul the bottom.

(vii) Tow it in this position for as long as possible. Six or eight hours is not too long a period. This procedure will stretch the sweep wire.

(viii) Hammer the last four turns on the winch drum together until they lie very tight indeed. Then heave in the sweep wire under tension, paying particular attention to the first layer of wire, and guiding it as evenly as possible on to the drum. Some jockey devices will guide the wire on well by themselves; others are virtually useless, and allow riding turns to develop, particularly near the shoulders of the drum. If in doubt it will generally pay to operate the jockey gear by hand, or use a tackle manned by a reliable assistant.

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* This is a starboard otter. For a port otter see Section 5avii above.

When a sweep wire has been stretched and wound on in this way the turns on the winch drum must be so tight that even the strain imposed when the wire subsequently fouls a wreck will not cause the wire to bite into them.

There is no reason why both sweep wires should not be prepared together. If they are, the otter and float on the windward side should be veered first and recovered last.

c. Adjusting the otter

Before an otter is used for sweeping it must be adjusted so that its tendency to dive is just correct. The adjustment is made with the bottle screw fitted in the lower legs of the otter slings, and it is controlled by noting the behaviour of the float, which tows on the surface above and slightly behind its otter.

If there is any choice a calm day should be chosen for the adjustment. The procedure is as follows:

(i) Stream the gear in the way set out in **b** above, veering about 150 fathoms of sweep wire. The float wire should if possible be of comparable length to that which will be used in future sweeping operations. If this is not known a length of about 8 or 10 fathoms will be satisfactory in most cases.

(ii) Once the gear is running reasonably at the speed at which it is intended to sweep, examine the float very carefully indeed through binoculars. If the bottle screw setting on the otter slings is correct a thin transparent film of water will cover its nose and this film will not break until it reaches the tabernacle which supports the flag. If the float rides lighter than this, or if the otter breaks surface, heave in the sweep and shorten the bottle screw. If the float tows with the flagstaff partly or wholly submerged, lengthen the bottle screw.

(iii) When the adjustment has been made satisfactorily, mouse all the otter sling shackles very carefully indeed, and note the setting of the bottle screw. Stow the otter in a place where neither it nor its slings can be damaged.

If the length of float wire used differs very greatly (say by more than 5 fathoms) from that which was employed in the initial adjustment, it may be necessary to reset the bottle screw in the otter slings. An otter will always tend to run more shallow as the length of float wire is increased.*

If there is any doubt concerning the adjustment it will always be prudent to err by making the float run too deep, rather than too shallow.

d. Changing the sweep wires end for end

In normal use the outer half of a sweep wire 450 fathoms long may well receive a great deal of wear, whilst the inner half (which spends most of its time wound on the drum) receives virtually no wear at all. The wear should be kept as even as possible by end for ending the wire from time to time. This may be done most easily by veering a float to the full length of the sweep wire, and then slipping the wire. The float may then be recovered, and the wire reeled on again under tension. This operation should be carried out over a flat sandy bottom for preference; mud and rock must be avoided, for obvious reasons.

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* The increased drag of the float wire tends to pull the otter over on its back, and lessens its tendency to dive. In an extreme case the otter will become unstable, and may well break surface.

7. Setting an Oropesa Sweep

A correctly set oropesa sweep must satisfy the following conditions:

(i) It must be as 'flat' as it is possible to make it. For any given length of sweep wire the ship's speed through the water must be adjusted so that the wire's natural tendency to sag is counterbalanced as much as possible by the upward thrust imparted to it by the action of the water on its lay.

(ii) The ship end of the sweep must be held at a constant and known depth by the action of the kite. The surveyor must know how much kite wire to veer to obtain any required depth.

(iii) The float end of the sweep must be held at this same depth by fitting a float wire of the correct length.

If a double sweep is being run, clearly there will be much more strain imposed on the kite than is caused by a single sweep. It will therefore be necessary to veer more kite wire to obtain any given depth setting.

A "Flat" Sweep

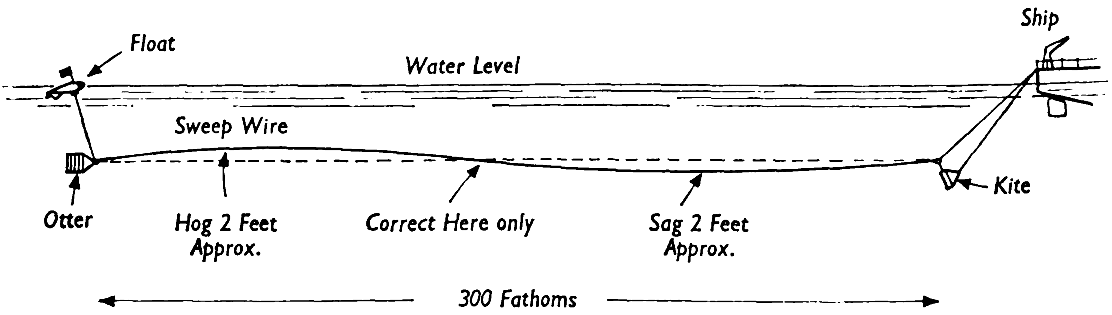

Fig. 4–12

a. Obtaining a 'flat' sweep

The term flat used in the context of oropesa sweeping is relative. No sweep can be truly flat for the whole of its length. The sort of thing that is likely to happen when the distance between the kite and the otter is 300 fathoms is illustrated in Fig. 4–12. For smaller distances the amounts of hog and sag should be less.

To obtain this so-called flat sweep the ship's speed through the water must be adjusted in accordance with the following table:

SPEED TO OBTAIN A FLAT SWEEP

AMOUNT OF SWEEP WIRE BETWEEN KITE AND OTTER IN FATHOMS	SPEED THROUGH WATER IN KNOTS	AMOUNT OF SWEEP WIRE BETWEEN KITE AND OTTER IN FATHOMS	SPEED THROUGH WATER IN KNOTS
100	6·2	250	8·7
125	6·6	275	9·1
150	7·0	300	9·5
175	7·4	325	9·9
200	7·8	350	10·3
225	8·3		

Note:

This table has been compiled from old records, which are not entirely consistent. No modern trials have been conducted to verify the quoted figures, or to find out the amounts of hog and sag in a 'flat' sweep, except when the distance between kite and otter is 300 fathoms. For these reasons the table may contain errors.

If the surveyor makes quite certain that his speed is not greater than the figures quoted (in practice it might well be prudent to aim at ½ knot less), no point in his sweep wire is likely to be more than a foot or two higher than he thinks, on this account.

Methods of finding out just what is happening along the whole length of the sweep wire are described in Section 8 below.

b. Setting the kite

The tables below give the depth of sweep for various kite wire settings and various speeds through the water, for single and double oropesa sweeps.

They have been compiled from data given in the *Addendum* (*Wire sweeping tables*) to the *Minesweeping Manual Volume* 1 (1953). The figures given in this addendum are the best that are available in 1968; they were obtained from the results of trials which have themselves become lost in the mists of antiquity. These figures, particularly those referring to the single sweep, are far from being consistent amongst themselves, and indicate that comparatively large systematic and random errors were present in the results of the original trials. They have been 'refined' by plotting them in the form of a large-scale graph, smoothing the various curves to make them consistent, and then re-tabulating values taken from the smoothed curves. Thus the tables given below are consistent and precise; they may or may not be very accurate, and the surveyor using them would be wise to test them at various points by making observations of his own.

Linear interpolation may be used quite safely in both the tables.

OROPESA WS MARK IV KITE WIRE TABLE
SINGLE SWEEP

AMOUNT OF KITE WIRE AWASH (FATHOMS)	SPEED THROUGH WATER, AND DEPTH OF SWEEP IN FATHOMS AND FEET							
	5 Kts.	6	7	8	9	10	11	12
9	5.0	4.5½	4.4					
10	5.4	5.3	5.2	5.0½	4.5½	4.4	4.3	
11	6.1½	6.0½	5.5½	5.4	5.3	5.2	5.1	5.0
12	6.5	6.4	6.3	6.2	6.0½	5.5½	5.4½	5.3½
13	7.2½	7.1	7.0	6.5	6.4	6.2½	6.1½	6.0½
14	7.5½	7.4	7.3	7.2	7.1	7.0	6.5	6.4
15	8.3	8.1½	8.0	7.5	7.4	7.3	7.2	7.1
16	9.0	8.4½	8.3	8.2	8.1	7.5½	7.4½	7.3½
17	9.3	9.1½	9.0	8.5	8.4	8.3	8.2	8.1
18	10.0	9.4½	9.3	9.2	9.1	8.5½	8.4½	8.3½
19	10.3	10.1½	10.0	9.5	9.4	9.2½	9.1½	9.0½
20	11.0	10.4	10.3	10.1½	10.0	9.5	9.4	9.3
21	11.3	11.1	10.5½	10.4½	10.3	10.2	10.1	10.0
22	12.0	11.4	11.2½	11.1	11.0	10.4½	10.3½	10.2½
23	12.3	12.1	11.5	11.4	11.2½	11.1½	11.0½	10.5½
24	12.5½	12.3½	12.2	12.0½	11.5	11.4	11.3	11.2
25	13.2½	13.0	12.4	12.3	12.2	12.0½	11.5½	11.4½
26	13.5	13.2½	13.1	12.5½	12.4½	12.3	12.2	12.1
27	14.1½	13.5	13.3½	13.2	13.1	12.5½	12.4½	12.3½
28	14.4	14.1½	14.0	13.4½	13.3	13.2	13.1	13.0
29	15.1	14.4	14.2½	14.1	13.5½	13.4½	13.3½	13.2½
30	15.3½	15.1	14.5	14.4	14.2½	14.1	14.0	13.5
31	16.0	15.3½	15.2	15.0½	14.5	14.3½	14.2½	14.1½
32	16.2½	16.0	15.4	15.2½	15.1	15.0	14.5	14.4
33	16.5	16.2½	16.0½	15.5	15.3½	15.2½	15.1	15.0
34	17.1½	16.5	16.3	16.1½	16.0	15.4½	15.3½	15.2½
35	17.4	17.1½	16.5½	16.4	16.2½	16.1½	16.0	15.5
36	18.0	17.3½	17.2	17.0½	16.5	16.3½	16.2½	16.1½
37	18.2½	18.0	17.4½	17.3	17.1½	17.0	16.5	16.4
38	18.5	18.2½	18.1	17.5½	17.4	17.2½	17.1	17.0
39	19.1½	18.5	18.3	18.1½	18.0	17.5	17.3½	17.2½
40	19.4	19.1½	18.5½	18.4	18.2½	18.1½	18.0	17.5
41	20.0½	19.3½	19.2	19.0½	18.5	18.3½	18.2½	18.1½
42		20.0½	19.4½	19.3	19.1½	19.0	18.5	18.4
43			20.0½	19.5	19.3½	19.2½	19.1½	19.0
44				20.1½	20.0	19.5	19.3½	19.2½
45						20.1	20.0	19.5
46								20.1

N.B. The depth of sweep is quoted to the nearest half foot only to enable the surveyor to determine the theoretical depth precisely. Of its very nature the sweep is most unlikely to run exactly at this depth.

Ch. 4

Oropesa WS Mark IV Kite Wire Table
Double Sweep

AMOUNT OF KITE WIRE AWASH (FATHOMS)	SPEED THROUGH WATER, DEPTH OF SWEEP IN FATHOMS AND FEET							
	5 Kts.	6	7	8	9	10	11	12
14	5.1	4.5½						
15	5.4	5.2	5.0½	4.5				
16	6.0	5.4	5.2½	5.1	5.0	4.5½		
17	6.2½	6.0	5.4½	5.3	5.2	5.1½	5.1	5.0
18	6.5	6.2	6.0½	5.5	5.4	5.3½	5.2½	5.2
19	7.1	6.4	6.2½	6.1	6.0	5.5	5.4½	5.3½
20	7.3	7.0½	6.4½	6.3	6.2	6.1	6.0	5.5½
21	7.5	7.2½	7.0½	6.5	6.3½	6.2½	6.2	6.1
22	8.1	7.4½	7.2½	7.1	6.5½	6.4½	6.3½	6.2½
23	8.3½	8.0	7.4	7.2½	7.1	7.0½	6.5½	6.4½
24	8.5½	8.2	8.0	7.4½	7.3	7.2	7.1	7.0½
25	9.1½	8.4	8.2	8.0½	7.4½	7.3½	7.3	7.2
26	9.3½	9.0	8.4	8.2	8.0½	7.5½	7.4½	7.3½
27	9.5½	9.2	8.5½	8.3½	8.2	8.1	8.0	7.5
28	10.2	9.4	9.1½	8.5½	8.4	8.2½	8.1½	8.1
29	10.4	10.0	9.3½	9.1½	8.5½	8.4½	8.3½	8.2½
30	11.0	10.2	9.5½	9.3½	9.1½	9.0	8.5	8.4
31	11.2	10.4	10.1½	9.5	9.3	9.2	9.1	8.5½
32	11.4	11.0	10.3½	10.1	9.5	9.3½	9.2½	9.1½
33	12.0½	11.2	10.5	10.2½	10.0½	9.5	9.4	9.3
34	12.2½	11.3½	11.1	10.4½	10.2½	10.1	9.5½	9.4½
35	12.4½	11.5½	11.3	11.0	10.4	10.2½	10.1	10.0
36	13.0½	12.1½	11.4½	11.2	10.5½	10.4	10.3	10.1½
37	13.2½	12.3½	12.0½	11.3½	11.1½	10.5½	10.4½	10.3½
38	13.5	12.5½	12.2	11.5	11.3	11.1	11.0	10.5
39	14.1	13.1½	12.4	12.1	11.4½	11.3	11.1½	11.0½
40	14.3	13.3½	13.0	12.3	12.0½	11.4½	11.3	11.2
41	14.5	13.5	13.1½	12.4½	12.2	12.0	11.4½	11.3½
42	15.1	14.1	13.3½	13.0	12.3½	12.2	12.0	11.5
43	15.3	14.3	13.5	13.2	12.5½	12.3½	12.1½	12.0½
44	15.5½	14.5	14.1	13.3½	13.1	12.5	12.3	12.2
45	16.1½	15.1	14.2½	13.5	13.2½	13.0½	12.4½	12.3½
46	16.4	15.3	14.4	14.0½	13.4	13.2	13.0½	12.5
47	17.0	15.4½	15.0	14.2	14.0	13.3½	13.2	13.0½
48		16.0½	15.2	14.3½	14.1½	13.5	13.3½	13.2
49		16.2½	15.3½	14.5	14.3	14.0½	13.4½	13.3
50		16.4½	15.5	15.1	14.4½	14.2	14.0	13.4½
51		17.0	16.1	15.2½	15.0	14.3½	14.1½	14.0
52			16.2½	15.4	15.1½	14.5	14.3	14.1½
53			16.4½	15.5½	15.3	15.0½	14.4½	14.2½
54			17.0	16.1	15.4½	15.2	15.0	14.4
55				16.3	16.0	15.3½	15.1	14.5½
56				16.4½	16.1½	15.5	15.2½	—
57				17.0	16.2½	16.0½	15.4	—
58					16.4	16.1½	15.5½	—
59					16.5½	16.3	16.0½	—
60						16.4	16.1½	—
61						16.5½	16.3	—
62							16.4½	—
63							16.5½	—

N.B. The depth of sweep is quoted to the nearest half foot only to enable the surveyor to determine the theoretical depth precisely. Of its very nature the sweep is most unlikely to run exactly at this depth.

c. Setting the otter

The table given below gives the depth of sweep for various lengths of float wire.

It has been compiled from data given in the *Addendum* (*Wire sweeping tables*) to the *Minesweeping Manual Volume* 1 (1953). The figures given in this addendum are the best that are available in 1968. They are more consistent than those given for the kite wire, but it is quite clear that they contain both systematic and random errors; they have been 'refined' in the same way as the kite wire figures (see **b** above) to obtain the present table, in which the figures are consistent amongst themselves, but not necessarily very accurate. The surveyor would therefore be wise to test the table at various points by making observations of his own. Linear interpolation may be used quite safely.

OROPESA WS MARK IV FLOAT WIRE TABLE

LENGTH OF FLOAT WIRE (FATHOMS)	SPEED THROUGH WATER, AND DEPTH OF SWEEP IN FATHOMS AND FEET							
	5 Kts.	6	7	8	9	10	11	12
4	5.0	5.0	4.5½	4.4½	4.3	4.1	4.0	3.5½
5	6.0½	6.0	5.5	5.3½	5.2	5.0	4.5	4.4
6	7.0	6.5	6.4	6.2	6.0	5.4	5.3	5.2
7	7.4½	7.4	7.2	7.0	6.4	6.2	6.1	6.0
8	8.2½	8.1½	8.0	7.4	7.2	7.0	6.5	6.4
9	9.0	8.5	8.3	8.1	7.5	7.3	7.2	7.1
10	9.3	9.2	9.0	8.4	8.2	8.0	7.5	7.4
11	10.0½	9.5	9.3	9.1	8.5	8.3	8.2	8.1
12	10.3	10.2	10.0	9.4	9.2	9.0	8.4½	8.3½
13	11.0	10.4½	10.2½	10.0½	9.4	9.2½	9.1	9.0
14	11.3	11.1	10.5	10.3	10.0½	9.4½	9.3½	9.2
15	12.0½	11.4	11.2	10.5½	10.3	10.1	9.5½	9.4½
16	12.3½	12.0½	11.4½	11.2	10.5	10.3	10.2	10.0½
17	13.1	12.3½	12.1	11.4½	11.1½	10.5½	10.4	10.2½
18	13.4½	13.0½	12.3½	12.1	11.3½	11.1½	11.0	10.4½
19	14.3	13.3½	13.0	12.3	12.0	11.3½	11.2	11.1
20	15.1	14.1	13.2½	12.5½	12.2	12.0	11.4½	11.3
21	15.5½	14.4	13.5½	13.2	12.4½	12.2	12.0½	11.5
22	16.4½	15.1½	14.2½	13.5	13.1	12.4½	12.2½	12.1
23	17.3	15.5	14.5½	14.1½	13.3	13.0½	12.5	12.3½
24	18.2	16.2½	15.2½	14.4	13.5½	13.3	13.1	12.5½
25	19.1	17.0	15.5	15.0½	14.2	13.5	13.3	13.1½
26	20.0	17.3½	16.2	15.3	14.4½	14.1½	13.5½	13.3½
27		18.1	16.5	15.5½	15.1	14.4	14.2	14.0
28		18.4½	17.2	16.2	15.3½	15.0½	14.4	14.2
29		19.2	17.5	16.5	16.0	15.3	15.0½	14.4½
30		20.0	18.2	17.1½	16,2½	15.5½	15.3	15.1
31			18.5	17.4	16.5	16.2	15.5	15.3
32			19.2	18.1	17.2	16.4	16.1½	15.5½
33			19.5	18.3½	17.4	17.0½	16.4	16.2
34			20.2	19.0	18.1	17.3	17.0½	16.4½
35				19.3½	18.3½	18.0	17.3	17.1
36				19.5½	19.0	18.2½	17.5½	17.3½
37				20.2	19.2½	18.5	18.2	18.0
38					19.5	19.1½	18.5	18.3
39					20.2	19.4	19.1½	18.5½
40						20.1	19.4	19.2
41							20.1	19.4½

N.B. The depth of sweep is quoted to the nearest half foot only to enable the surveyor to determine the theoretical depth precisely. Of its very nature the sweep is most unlikely to run exactly at this depth.

8. Calibrating an Oropesa Sweep

It has been seen in Section 7 above that the tables used for setting the kite and otter are not as accurate as the surveyor would wish. Furthermore the sweep itself is not really flat, even when the ship is proceeding at the speed which produces a so-called flat sweep. Slight differences in the manufacture of the otters and kites may also cause differences in the depth keeping qualities of a sweep between one ship and another.

Clearly each surveyor must calibrate his sweep for himself, if he is to use it with confidence. In its simplest form a calibration might well consist of finding out the maximum departure of any part of the sweep from the depths given in the tables in Section 7 above. The sweep settings could then be adjusted so that no part of the wire could be running shallower than the desired sweeping depth; some parts might perhaps be running anything up to two fathoms deep. Such a calibration would be perfectly adequate if the sweep was to be used as a clearing sweep. If greater precision in depth setting was required, then the calibration would necessarily have to be more rigorous.

Referring to Fig. 4–12, the depth of the sweep wire must be determined at at least five points if the shape of its curve in the vertical plane is to be determined with reliability. These points are at the kite, one-quarter, one-half and three-quarters of the way along the wire, and at the otter respectively.

Three methods may be used to obtain a calibration. They are described below. In every case the ship must proceed on a steady course at a steady speed whilst the calibration observations are taken.

a. Calibrating with a depth recorder

The depth recorders used by minesweepers to determine the depth of their sweeps may be used by the surveyors to obtain a fairly crude calibration. These recorders, and their method of use, are described in *Volume II* of the *Minesweeping Manual, 1963 Edition.*

They may be attached by a short wire strop to various parts of the sweep, and will then provide a trace of depth against time on a roll of specially sensitised paper. Each recorder must itself be calibrated before it is used on the sweep, since the record paper does not carry scales of depth or time, and the springs used to measure pressure vary slightly from recorder to recorder. One of four interchangeable springs is fitted in a recorder, depending on the depth it is desired to measure. On the record paper a change in depth of one fathom will be represented by a distance varying between about one-quarter of an inch (for the weakest 12 fathom spring) to about one-sixteenth of an inch (for the strongest 50 fathom spring).

Since the surveyor calibrating his oropesa sweep wants to know how it behaves at the five points mentioned above, he will need at least five depth recorders if the process of calibration is not to become lengthy and tedious. These may or may not affect the behaviour of the sweep, with their added weight. They are not likely to provide him with information accurate to within less than about two feet, for depths of less than 12 fathoms; at greater depths their accuracy will fall off, until at depths of 30 to 50 fathoms they are not likely to detect changes of 1 fathom with any certainty.

Depth recorders should not be used if either of the methods set out in **b** and **c** below can be employed instead.

b. Calibrating by echo sounder

In reasonably calm weather an echo sounder will detect the wire of an oropesa sweep as it passes over it. A pair of surveying vessels may therefore calibrate each others oropesa sweeps in the following way:

(i) Vessel *A*, whose sweep is to be calibrated, sets it 'flat' and at a certain depth, using the information tabulated in Section 7 above.

(ii) Vessel *B*, whose speed must be greater than that of *A* when she is towing a sweep, approaches *A* from the quarter, and passes over the sweep just ahead of the otter float, noting its depth by echo sounder as she does so.

(iii) She then adjusts her course and speed so that she crosses and re-crosses the sweep wire at several points between the otter and a point as close to *A*'s kite as she can prudently approach, noting the depth by echo sounder each time the sweep wire appears on the trace.

(iv) Fixes may be obtained by observing gyro bearings, and horizon dip angles or range finder ranges into *A*.

(v) The vessels may then exchange their roles, to calibrate *B*'s sweep.

The more observations that can be obtained, the better will be the check on the performance of a particular sweep, and the accuracy of the tables.

If another vessel is not available, then a ship's boat may be used. But since the minimum speed required to obtain a flat sweep is just over six knots, and since not many boats are likely to be able to steam much faster than this and still obtain a good echo trace, it may well be necessary to modify the procedure and accept the fact that a good calibration will take much longer to obtain.

This method, using two ships, will produce a calibration more quickly than either of the other two methods described here; its accuracy will be greater than that obtained with depth recorders, and equal to that obtained by the dip-stick method described in **c** below. It is recommended that it should be used whenever possible.

c. Calibrating by dip-stick

If a metal rod is covered with a good coating of paint, and then suspended in the path of an oncoming oropesa sweep at the correct depth, the sweep wire will mark the wet paint where it strikes the rod.

In practice rods between 12 and 15 feet in length have been found to be suitable. They may be attached to a lead line, and suspended from a boat, which should preferably have a low free-board so that it will not be affected too much by wind drift. If the weather is not quite calm it may be necessary to use a sea anchor to reduce this drift, so that the leadline will remain up and down.

The observers in the boat will notice when the sweep strikes their dip-stick; they should immediately signal to the ship, so that their relative position may be fixed.

This method of finding the depth of a particular part of an oropesa sweep provides accurate results, but it does not produce them nearly so fast as that described in **b** above, unless several boats can be used to obtain simultaneous observations at different points of the sweep wire.

9. Operation and Management of the Oropesa Sweep

Although the use of double oropesa sweeps veered to their maximum length of 350 fathoms may appear to be very attractive, the surveyor will usually find that a comparatively short single sweep (perhaps between 150 and 250 fathoms long), used intelligently, will produce more work in a given time. The short single sweep is much more handy, its float wires can be changed in a much shorter time, and it will place far fewer restrictions on the manoeuvring of the sweeping vessel. If there is any doubt at all the surveyor is strongly recommended to use it, particularly if he is working in restricted waters or in a tideway.

Good communications between bridge and sweepdeck are vital to all sweeping.

a. Streaming the sweep

When the otters and kites have been adjusted properly, the sweep may be streamed in the following way:

(i) Having connected a float wire of the correct length, stream the otter and the float in the manner described in Section **6b** above. In a well practised vessel, the float and otter may be slipped at speeds of up to 6 knots; if in doubt it will always be wise to do this too slowly rather than too fast. Veer the sweep wire to about 30 fathoms. The amount of wire out may be measured with the hand held measurer, and checked as each 50 fathom mark comes off the winch; the winch dials are not usually very accurate.

(ii) If a double sweep is to be used, stream the windward sweep first, and recover it last.

(iii) When one or both sweeps are in this 'short stay' position, with 30 fathoms veered, no restrictions need be placed on the manoeuvring of the ship, and her turning circle will be affected very little. From this position it may take anything up to 10 minutes to veer 250 fathoms of sweep wire and lower the kite.

(iv) Once the sweep is running correctly, increase speed as desired up to that which will produce a flat sweep, and veer the sweep wire on the brake. Do not hurry this operation, and always keep the float moving nicely through the water; if it falls too far astern, apply the brake until it pulls out on the quarter once more. Snatch the kite pendant on to the sweep wire when the latter has been veered to perhaps 50 fathoms less than its final length; the brake must be applied as this is being done.

(v) Lower the kite (see Section **6a** above) to a depth of about 4 or 5 fathoms. There is no need to reduce speed, provided the kite has been properly adjusted. The kite and sweep wires should be veered together.

(vi) Adjust the sweep wire as necessary, and then veer kite and sweep wires together again until the correct amount of kite wire is awash. The length of sweep wire quoted in all the relevant tables is that between the kite and the otter. It is not really critical to within a fathom or two; but the amount of kite wire is, and it may be necessary to adjust it from time to time as the ship's speed through the water alters slightly.

(vii) The sweep is now set for running. The sweep wires should be towed on the brakes, and these should be set up just enough to prevent the wires from rendering, and no more. Kite and sweep wire lengths should be altered together, whenever this is possible, in order to reduce the strain on the kite block and pendants.

b. Manoeuvring with the sweep set

Small alterations of course, up to about 20°, may safely be made with the sweep (or sweeps) set for running; they should be made gently.

If large alterations are to be made, special steps must be taken to reduce the strain on the gear as much as possible. The following notes may be used as a guide to the exercise of prudent seamanship.

(i) It will always be prudent to raise the kite to its 'short stay' depth of perhaps 4 or 5 fathoms.

(ii) When the turn is away from the side on which the sweep is streamed, the float should be kept just outside the ship's wake. Too tight a turn will bring the float inside the wake, introduce a large bight in the wire, cause it to sag excessively, and put a great strain on the gear once the ship steadies on her new course.

(iii) When the turn is towards the side on which the sweep is streamed, the helm must be applied and eased so that the float never comes less than two points abaft the beam. This is a very stringent condition, and will mean that the ship's turning circle is very large with a long sweep. It may help if the sweep wire is heaved in whilst the turn is being made.

A turn made away from a short single sweep may be comparatively tight, and will be completed quickly. It should always be used if possible. Clearly the double sweep will be unwieldy, whichever way the ship may turn.

c. Allowing for the height of the tide

A perfect oropesa sweep would run at a 'fixed' depth below chart datum, and the float wires and kite wire would be easily adjusted every time the tidal reduction changed by one foot. Although the length of the kite wire is easily altered, it is not possible to change the float wire without recovering the otter, and this cannot be done too frequently or very little actual sweeping will be accomplished. The surveyor must use his judgement and experience to arrive at a prudent compromise between quantity and quality. The following points may be helpful:

(i) If the sweeping takes place over the high or low water period, one setting of the sweep will last a comparatively long time. The worst time to sweep will be at half tide. Clearly the less the tidal range is the better.

(ii) So long as the sweep is not running shallower than the surveyor thinks, all will be well. He may therefore change his settings whenever the reduction alters by six feet or so, always making certain that the sweep will be running deeper than the reduction would indicate.
Example:

Height of tide at 0940 = 12 *feet*
Height of tide at 1100 = 6 *feet*

The sweep is required to run at seven fathoms below chart datum. Therefore the surveyor may set his sweep to nine fathoms at 0940, and to eight fathoms at 1100. At 1059 he will be sweeping one fathom deeper than the figures would indicate.

(iii) When a clearing sweep is being carried out, there is plenty of water, and he does not expect to encounter any obstructions, the surveyor may add the maximum reduction during the day to the depth at which he is required to sweep, add an additional fathom to take care of the inaccuracies of the sweep itself, and then use fixed float wire and kite settings all day. He will at times be sweeping considerably deeper than he need, but at no time will his sweep be running at a depth less than that required.

This method has been used extensively in the past, and it can be recommended.

d. Fixing the ship and the float; the approximate spread of the sweep

A sweeping vessel may be fixed by any of the methods suitable for sounding. The scale of the plot must be large enough to enable the overlaps between adjacent swept lanes to be nicely plottable; if the scale is too small these overlaps (on the ground) will have to be larger than is necessary, and output will be smaller than it need be. Electronic fixing systems, e.g. Decca and HiFix, are particularly suited to oropesa sweeping operations, since they indicate the ship's position continuously. Tartan plots may sometimes be used to advantage, particularly on isolated wrecks and obstructions.

Sweeping operations on an isolated wreck or obstruction may also be controlled by sonar, the ship being manoeuvred on sonar ranges and bearings so that the middle of the sweep wire passes over the wreck. The beam range will provide confirmation that a wreck has been well covered by the sweep.

The position of the float, and hence that of the far end of the sweep, must always be observed from the ship whenever a fix is obtained, and more frequently if the ship's head is not steady. This may be done most simply by observing gyro bearings and horizon dip angles; a range finder may be used, but is not likely to be so sensitive as a sextant. On no account may the position of the float be inferred from the amount of sweep wire veered.

When planning how best to sweep the surveyor may well wish to know what the approximate spread of an oropesa sweep will be for any given length of sweep wire. The table below sets out this relationship. The figures given in it must never be used in an attempt to fix the float relative to the ship; they will be valid only if there is no cross component of the tidal stream (see **e** below).

OROPESA WS MARK IV

LENGTH OF SWEEP WIRE AND APPROXIMATE SPREAD OF A SINGLE SWEEP

LENGTH OF SWEEP WIRE IN FATHOMS	APPROXIMATE SPREAD OF A SINGLE SWEEP IN YARDS
100	105
150	142
200	170
250	192
300	208
350	220

e. Making the best use of the tidal stream

In Fig. 4–13 the ship is steering 080° at seven knots. Since the tidal stream is setting towards 142° at two knots, her course made good is 092½°.

Suppose to start with that both oropesa sweeps are veered to 300 fathoms, as indicated by the firm lines. The total effective swept path is $5x$, but the starboard (down tide) sweep will contribute four-fifths of this amount ($4x$) and the port (up tide) sweep only one-fifth (x). In still water the total effective swept path would be a little more than $5x$ and each sweep would contribute half this amount.

If the sweep wires are shortened in to 150 fathoms, the starboard (down tide) sweep will still contribute very much more ($2\frac{1}{2}x$) than the port sweep (x) towards the total effective swept path of $3\frac{1}{2}x$.

Note that nothing at all is gained in this case by increasing the length of the port sweep from 150 to 300 fathoms.

In a tideway most of the useful work will always be done by the down tide sweep. Since to run a double sweep is generally difficult and awkward, it will often be attractive to take advantage of this fact and run a single sweep in the way which makes most use of the tidal stream.

The following guiding principles may be laid down:

(i) Use whichever sweep will be on the down tide side of the ship.

(ii) If possible put the direction of flow of the stream abaft the beam, preferably so that it cuts the sweep wire at right angles. A tidal stream on the bow will not be very helpful.

(iii) Veer as much sweep wire as possible.

(iv) Do not proceed too fast, so that the tidal stream will have plenty of effect.

Requirements (iii) and (iv) are, of course, mutually conflicting, since the more wire that is veered the faster will the ship have to proceed to obtain a flat sweep. Common sense must be used to obtain a reasonable compromise; if in doubt the surveyor should

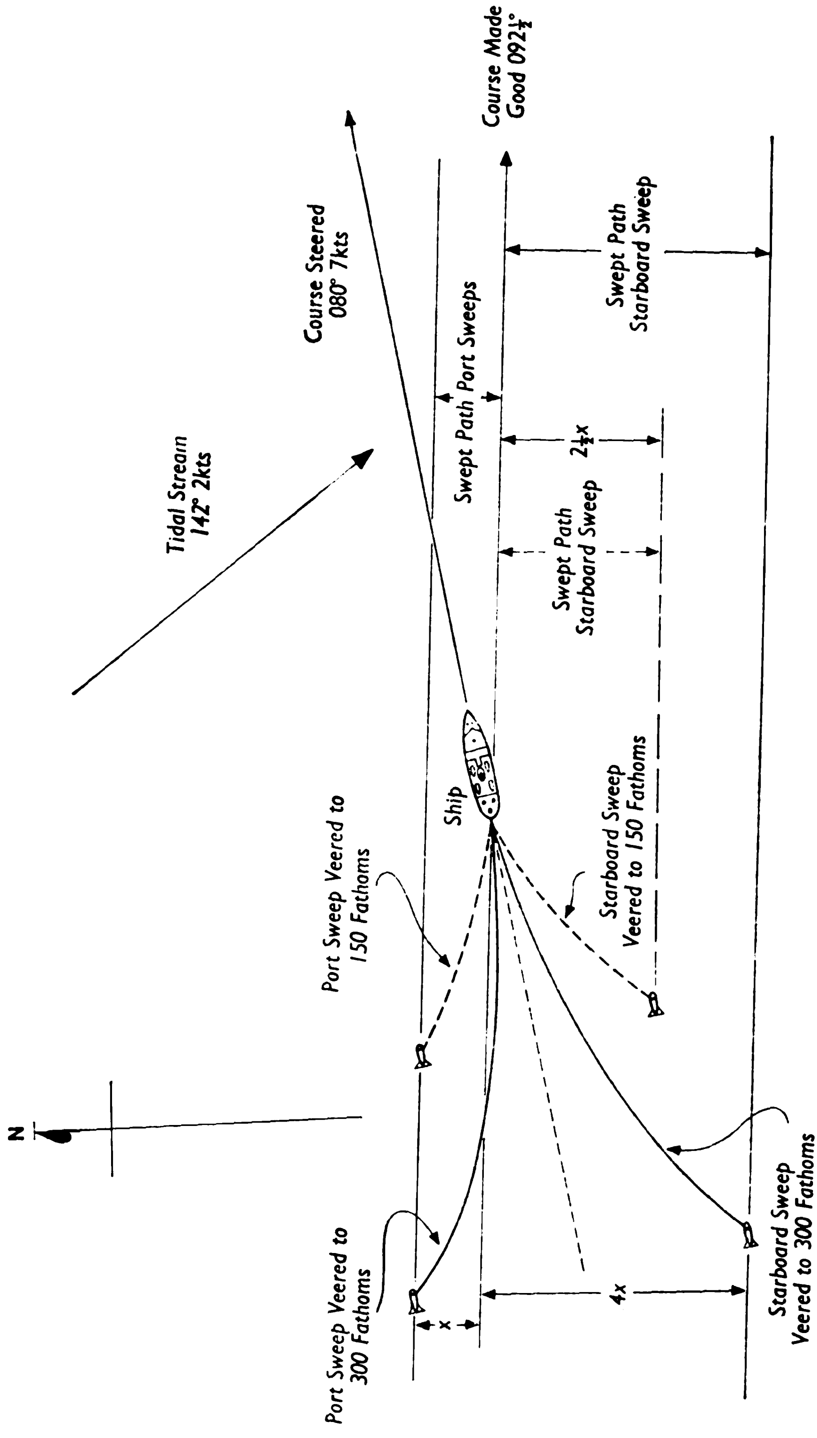
Course Made Good 092½°
Course Steered 080° 7kts
Swept Path Starboard Sweep
Swept Path Port Sweeps
Tidal Stream 142° 2kts
2½x
Swept Path Starboard Sweep
Ship
Port Sweep Veered to 150 Fathoms
Starboard Sweep Veered to 150 Fathoms
N
Port Sweep Veered to 300 Fathoms
x
4x
Starboard Sweep Veered to 300 Fathoms

Fig. 4–13

err by using too short a sweep. In practice sweep lengths of between 150 and 250 fathoms have produced excellent results.

The surveyor clearing a large area by oropesa must decide himself whether to use both sweeps continuously, perhaps disregarding the tidal stream, or whether to use each sweep in turn as he proceeds up and down his planned lines. The latter method lends itself well to the changing of the float wire setting, to allow for tidal reduction, as the sweeps are changed round at the ends of the lines.

Whilst the placing of the tidal stream on the disengaged quarter speeds up the progress of single oropesa sweeping very considerably, it may place the surveyor in an awkward position if his sweep fouls an obstruction and he is not very quick in taking remedial action. In a well trained vessel a foul of this nature produces an exhilarating feeling of being completely in control of a difficult situation; in a badly run ship it may well result in a long sweep wire running out to a clench and being lost.

f. Dealing with a fouled sweep

When a sweep fouls, the ship must be stopped relative to the sea bed (not the water) before the sweep wire remaining on the winch runs out to a clench, and in such a way that the wire fouls neither the screws nor the rudder. The shorter the sweep, and the slower the ship's speed, the more time will there be for remedial action. It will always be vital that both bridge and sweep deck should know precisely what is to be done in any given situation, do it quickly without waiting for instructions, and work in the closest harmony.

(i) Detecting a foul. If the sweep fouls an obstruction the float will almost certainly 'alter course' and head in at high speed towards a point directly astern; it may or may not become submerged. It is very probable, but not necessarily certain, that the sweep wire will begin to render off the winch at the same time.

Abnormal behaviour of the float is generally detected most easily from the bridge, whilst the behaviour of the sweep wire will clearly be noticed first on the sweep deck.

If the otter, or the bight of the sweep wire, touches the bottom, the winch may well render. This situation can only occur if the sweep is set too deep or is being run too slowly. The remedy is to hold on to the sweep wire and increase speed; since this is the worst action to take in the event of a real foul, it is most important that the two situations should never be mistaken one for the other.

(ii) Fouled sweep; tidal stream slack. If the tidal stream is slack, or very nearly so, it will be best to stop the ship over the ground by going directly astern on the engines. To start with the winch should be allowed to render the sweep wire freely; once the engines are going astern judicious use of the brake will assist in bringing the ship up as quickly as possible.

As the strength of the stream increases, there will come a time when the action described in **(iii)** and **(iv)** below will be preferable to that set out above.

(iii) Fouled sweep; tidal stream on the bow. In Fig. 4–14(*a*) the ship at *A* has just fouled an obstruction with her starboard sweep wire. The tidal stream is coming from the port bow.

She should immediately stop engines and turn to port as indicated by the pecked line, rendering the sweep wire freely as she does so. The aim must then be to stop the ship over the ground as quickly as possible, with the tidal stream fine on the starboard bow, at *B* in the figure. The engines may be put astern and the winch brake used judiciously as necessary. The kite should be recovered as soon as possible. The ship will still be moving through the water at *B* (she must on no account lose way entirely or the sweep wire may foul the rudder) and can use her engines and rudder to move over to *C*, heaving in the sweep wire carefully as she does so. In most cases the sweep will clear when the ship arrives at *C*; if it does not she must proceed further down tide and to the left, turning to port as she does so. In the extreme case, when the foul persists, she will finish up hanging down tide from the foul on her sweep wire.

The ship must on no account allow herself to be set down tide from her original course line until she has reached position *C* in the diagram.

If, for any reason, the surveyor is using his starboard sweep with the tidal stream on the starboard bow (his rate of output would be very low indeed) when the foul occurs, he may act as though the tidal stream were slack.

(iv) Fouled sweep; tidal stream on the quarter. In Fig. 4–14(*b*) the ship at *A* has just fouled an obstruction with her starboard sweep wire. The tidal stream is coming from the port quarter.

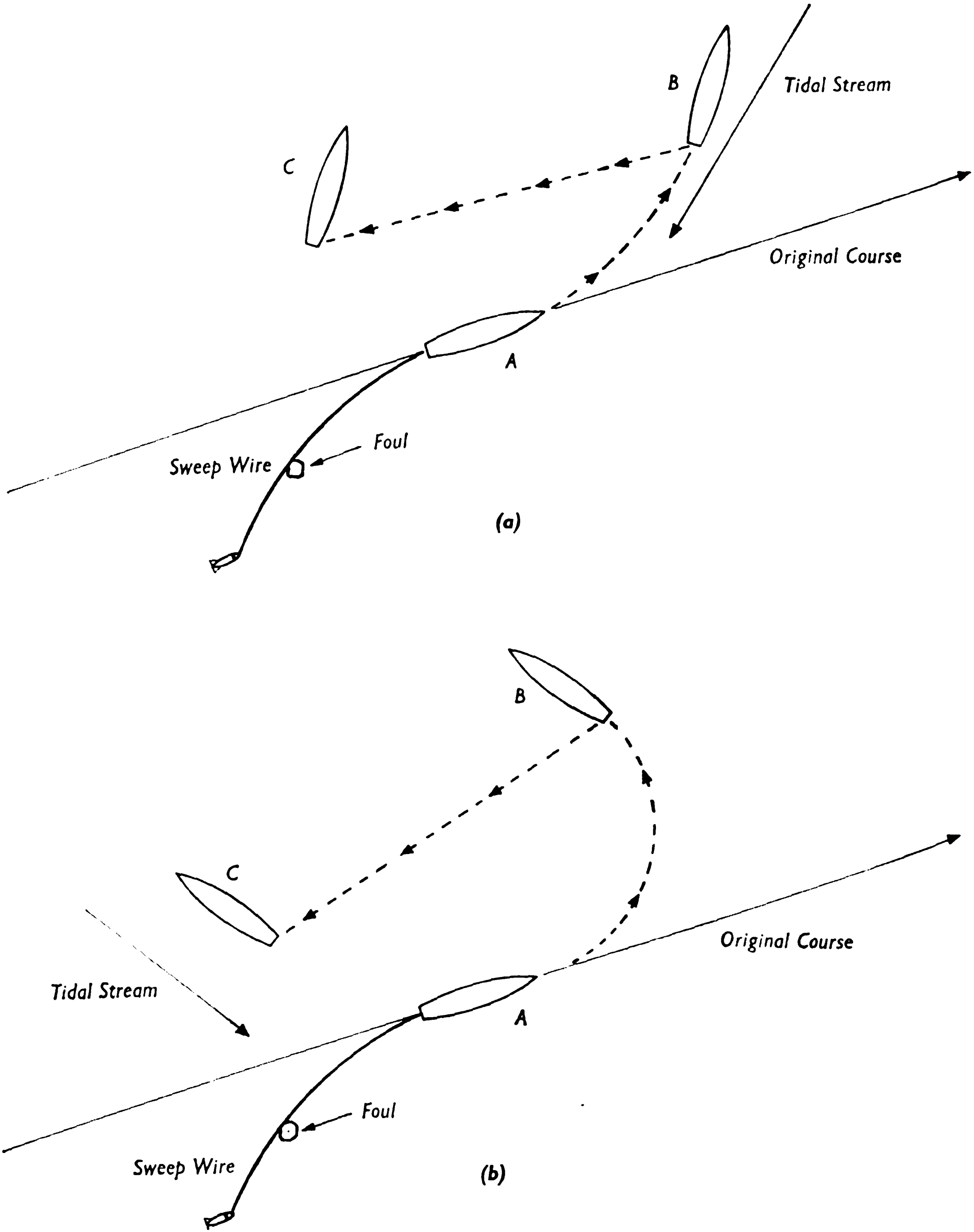

Fig. 4–14

She must turn to port as quickly as she can, and go astern so that at *B* she is stopped over the ground, with the tidal stream fine on the starboard bow. It will be better to turn too far and too fast, rather than not far enough and too slowly. The sweep wire must be rendered quite freely until the ship arrives at *B*; if any strain is put on it, it will slow up the vital turn into the tidal stream. The kite should be recovered as soon as possible.

From *B* the ship may move across the tide to *C*, heaving in the sweep wire carefully as she does so. If the foul does not clear when she arrives at *C*, then the remedy described in **(iii)** above must be applied.

As before the ship must on no account allow herself to be set down tide from her original course line until she has reached position *C* in the diagram.

(v) Fixing the foul. When a foul occurs the necessity to take immediate remedial action will generally make it impossible to obtain a fix. This does not matter, since a very good idea of the position of the sweep wire and the otter can always be obtained by plotting on from the last routine fix. However, as soon as it does become possible, it will always be wise to obtain a fix in the ship, and a bearing and distance to the float, and to go on doing these things at frequent intervals until the foul clears itself or the surveyor is quite satisfied concerning its position.

It should always be remembered that the float does not necessarily mark the position of the foul. Any part of the sweep wire may foul, and in certain circumstances be held fast in a wreck or obstruction.

(vi) Clearing a foul. It is assumed here that the ship has arrived at *C* in Fig. 4–14(*a*) or (*b*), and that the sweep wire remains fast in the obstruction.

If the float is still on the surface it may be either close down tide of the obstruction, or some way down tide, depending upon which part of the sweep wire is held fast. A fix obtained at *C* will probably give a good indication of the actual situation underwater.

Unless the surveyor is certain that it is not, he will always be wise to assume that the obstruction will be a danger to his own vessel. He should therefore be careful to give the float a reasonably wide berth as he manoeuvres round it (see **(iii)** above), and particularly whilst he still remains up tide of it. Once he is stopped down tide of, and stern on to the obstruction, he may heave in the sweep wire gently, using the engines to help if necessary.

By this time he must have decided whether he is prepared to take his vessel over the obstruction or not. If he is he may heave in until the sweep wire either comes away clear with the otter and float, or parts; in some cases where the foul persists it may be prudent to cut the sweep wire before it parts. If he is not prepared to go over the obstruction he must cut the sweep wire in any case.

It should then be possible to recover the float, and perhaps the otter from the ship or with a boat.

If the float has been pulled under, and the sweep has not cleared by the time the ship arrives at *C* in Fig. 4–14, it will generally be wise to cut the sweep wire straight away. The float may be recovered by running a new sweep set fairly shallow through its last known position; usually the float wire will be cut, but with luck the float and otter may come away from the obstruction intact.

It must be stressed that the clearing of a badly fouled sweep demands a high standard of seamanship, and the exercise of prudence and common sense. The methods outlined in this sub-section have all been used successfully in the past, but this does not mean that they should be used blindly in the future.

10. The WS Mark V Oropesa Sweep

The WS Mark V sweep is a lighter version of the Mark IV sweep, which is fitted in some smaller surveying vessels, it is used only as a single sweep.

It can be streamed and recovered by hand, about eight men being required. It is operated in the same way as the Mark IV sweep, and all the information given in Sections 5 to 9 above, with the exception of the tables, is relevant. Sweep wire lengths of between 75 and 150 fathoms have been used in the past. The tables give below are valid only if the sizes of the various wires are as follows:

Sweep Wire	¾ inch B.M.M.W.
Kite Wire	1¾ inch F.S.W.R.
Kite Pendants	1 inch F.S.W.R., length 4½ feet
Float Wires	1 inch F.S.W.R.

They have been constructed from the results of trials carried out in H.M.S. *Echo* in 1958. The observations on which the kite and float wire figures depend were consistent amongst themselves, and indicate that errors should not exceed a foot or two. The tables showing the theoretical spread of the sweep, and that indicating the various speeds necessary to obtain a 'flat' sweep, are based on a few observations only, and are not entirely reliable.

When using the sweep the surveyor should lose no opportunity to check these tables, using the methods already described.

Linear interpolation may be used in all the tables.

OROPESA WS MARK V
KITE WIRE TABLE
SINGLE SWEEP

AMOUNT OF KITE WIRE AWASH (FATHOMS)	SPEED THROUGH WATER, AND DEPTH OF SWEEP IN FATHOMS AND FEET		
	4 kts.	5 kts.	6 kts.
9	4·0	3·5	3·4
10	4·3	4·1	4·0
11	4·5	4·4	4·2
12	5·2	5·0	4·4
13	5·5	5·3	5·0
14	6.2	5·5	5·2
15	6.5	6.2	5·4
16	7.1	6.4	6.1
17	7·4	7·1	6.3
18	8.1	7·4	6.5
19	8.3	8.0	7.1
20	9·0	8.3	7·3
21	9·3	8.5	7·5
22	9·5	9·2	8.1
23	10.2	9·4	8.3
24	10.5	10.1	8.5
25	11.2	10.4	9.1
26	11.5	11.0	9·3
27	12.1	11.2	9·5
28		11.5	10.2
29		12.2	10.4
30			11.0
31			11.2
32			11.4
33			12.0

N.B.: The depth of sweep is quoted to the nearest foot only to enable the surveyor to determined the theoretical depth precisely. Of its very nature the sweep is most unlikely to run exactly at this depth.

OROPESA WS MARK V
FLOAT WIRE TABLE

LENGTH OF FLOAT WIRE (FATHOMS)	SPEED THROUGH WATER, AND DEPTH OF SWEEP IN FATHOMS AND FEET		
	4 kts.	5 kts.	6 kts.
4	4.0	3.4	3.3
5	5.0	4.4	4.2
6	6.0	5.3	5.0
7	6.4	6.1	5.4
8	7.2	6.5	6.1
9	8.0	7.2	6.4
10	8.4	8.0	7.1
11	9.2	8.3	7.4
12	9.5	9.0	8.1
13	10.2	9.3	8.4
14	11.0	10.0	9.0
15	11.3	10.3	9.3
16	12.0	11.0	9.5
17	12.3	11.3	10.2
18		12.0	10.5
19			11.1
20			11.3
21			12.0

N.B.: The depth of sweep is quoted to the nearest foot only to enable the surveyor to determine the theoretical depth precisely. Of its very nature the sweep is most unlikely to run exactly at this depth.

OROPESA WS MARK V
SPEED TO OBTAIN A FLAT SWEEP

AMOUNT OF SWEEP WIRE BETWEEN KITE AND OTTER IN FATHOMS	SPEED THROUGH WATER IN KNOTS
75	3.5
100	4.0
125	4.6
150	5.4

N.B.: This table is based on a few observations only, and is not entirely reliable. It should be checked in the field if possible.

OROPESA WS MARK V
LENGTH OF SWEEP WIRE AND APPROXIMATE SPREAD OF A SINGLE SWEEP

LENGTH OF SWEEP WIRE IN FATHOMS	APPROXIMATE SPREAD OF A SINGLE SWEEP IN YARDS
75	73
100	100
125	120
150	133

Ch.

Part 3 Drift and Drag Sweeping

11. Introduction; Definitions

A drift sweep consists of a horizontal wire, which is suspended at a known depth below a vessel,* or between two vessels, and which remains stationary relative to the water. Vessels using a drift sweep depend upon the tidal stream or current to carry them over a wreck or obstruction. True drift sweeping, which is the most precise form of sweeping at present (1968) available to the surveyor, can only be carried out when the wind is so light that the sweeping craft are not affected by it appreciably when they are stopped in the water. If the wind is strong enough to cause a vessel to drift to leeward, the sweep too will be moving through the water, and will become a drag sweep; it will then be necessary to take into account the fact that the sweep lowering lines no longer remain straight, and to make an allowance for this if necessary.

A drag sweep consists of a 'drift' sweep which is either intentionally towed very slowly through the water, or moves through the water of its own accord under the influence of wind drift. This movement through the water makes it more difficult to set the sweep to a certain depth; it also affects the behaviour of the sweep wire itself, so that it may well no longer remain horizontal throughout its length. For these reasons drag sweeping is not so precise as drift sweeping.

The width of a drift sweep will depend either on the length of the vessel using it, or the prudent length of the unsupported bight of sweep wire if two vessels are being used. It will usually vary between about 150 and 400 feet. Most drag sweeps used in the surveying service of the Royal Navy have a similar width. It is possible to run a drag sweep much wider than this, however, and some surveyors use a sweep wire which may be anything up to half a mile long. As will be seen below, it is not possible at present to combine precision and great width of sweep in one and the same sweep.

Drift and drag sweeps cover the ground slowly. For this reason they cannot compete with the oropesa sweep in clearing large areas, provided the latter can be used. Neither can they compete with an experienced diver in finding the least water over a wreck or obstruction of small extent. They are especially suited to the precise clearing of wrecks and obstruction of small extent, when a diver cannot be used.

Before he starts a drift or drag sweep, the surveyor should always carry out a careful examination with echo sounder and sonar, so that he knows exactly where the wreck or obstruction lies, and has a good idea of its extent and orientation.

12. Working Scales; Fixing; General Control

The scale of a drift or drag sweeping plot must always be so large that errors of fixing and plotting will be small compared with the width of the sweep. Natural scales of 1/2400 (1 inch to 200 feet) and 1/3600 (1 inch to 300 feet) have been used with success in the past; they are easy to use and sufficiently large for most purposes.

The method used for fixing must be capable of detecting movements of the order of 5 or 10 feet. It need not provide absolute positional accuracy, so long as it remains consistent whilst the sweeping is being carried out. For instance, a wreck might well be drift swept using Hi-Fix as control; the phase lag and fixed errors of the Hi-Fix could be neglected so long as they remained constant whilst the sweeping was being carried out; the absolute position of the wreck could be determined quite separately. If floating marks or electronic aids are used for fixing, the surveyor must take great care that this relative accuracy is in fact maintained. On no account may he assume that the errors of the position given by the 'black box' will remain constant, or that floating marks will not swing round their moorings, however taut these may be. The wreck or obstruction itself will always provide the best check fix, provided it can be identified with certainty. Transits, check sextant fixes, and very tautly laid pellets, may all be used as additional controls on the fixing in difficult circumstances. Where there is doubt the overlaps between adjacent swept paths must be increased so that they more than compensate for any possible errors of fixing.

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* This word is used here in its widest sense, to denote any man-made object that will float; it includes ships, boats and floating booms.

When the tidal stream is being used to set a drift sweep over a wreck, the surveyor will often find it helpful to lay a dan buoy in a convenient position up tide of the wreck or obstruction. This buoy may then be used as a visual reference mark from which to start the various sweeps; it should be fitted with a floating tail of corks or pellets, to indicate the direction of flow of the stream. Sweeping operations should be completed whilst the tidal stream is flowing in one direction, if this is possible. Where the streams are rotary difficulties in controlling the various drifts are almost certain to arise, and it may on occasions be necessary to sweep for only a short period each day, making use of a particular direction of flow of the tidal stream.

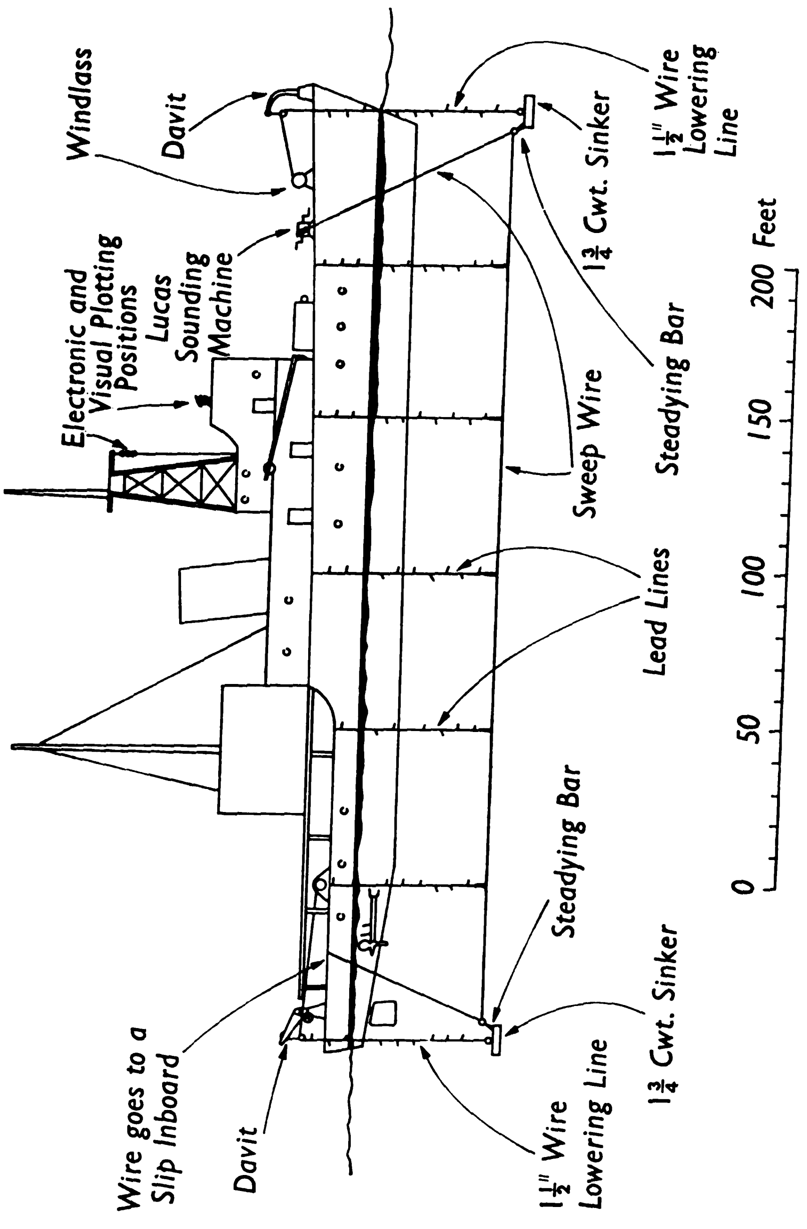
13. Drift and Drag Sweeping from a single Vessel

a. Equipment and rigging

The equipment and rig used will depend on the type of vessel which is available to the surveyor, and the special nature of the work to be carried out. The ship-borne surveyor will generally prefer to use his ship if possible. Special circumstances may sometimes force him to use a boat, or a floating boom. The land based hydrographic surveyor is more likely to use a small craft or floating boom.

(i) Equipment and rig in a ship. Figure 4–15 shows a ship rigged for drift sweeping. The sweep in this case is set to starboard, and the ship will be handled so that she drifts to port; therefore if and when the sweep wire fouls, the gear will grow away from the ships side, clear of the screws and any other underwater fittings. The sweep wire may be made of the piano wire normally used on sounding machines, seven stranded Kelvin sounding machine wire, or even spun yarn. All have been used successfully in the past. The essential aim is to use something which does not part too easily when the sweep fouls. In this particular rig the sweep wire comes off a Lucas sounding machine forward, and passes through a shackle which is attached to the steadying bar on the forward sinker; it then passes through eyebolts which have been screwed into the bases of the leads, which are attached to the wire-hearted leadlines, through a shackle on the end of the after steadying bar, and up and inboard to a slip on the quarter deck. The various lines supporting the sweep wire should be not more than about 50 feet apart. The two steadying bars, which should be about two feet long, are welded or bolted to the main sinkers; their purpose is to prevent these sinkers from spinning, and wrapping the sweep wire round the lowering lines; they will not, of course, do this properly unless the sweep wire is kept under reasonable tension all the time. The main lowering lines and the leadlines should be marked every foot, in the manner of an ordinary sounding leadline, so that they indicate the depth of the sweep wire directly.

There must be good communications between the bridge and the forward and after lowering line handling positions. The Lucas sounding machine operator should if possible be directly visible from, and within talking distance of the bridge.



A Ship's Drift Sweep Set to Starboard

Fig. 4-15

The intermediate leadline positions should if possible be sited so that they too can be seen from the bridge; instructions may be passed to the leadline operators by inter-com or loud hailer.

Ten men are needed to set the sweep in the figure quickly and efficiently, two on either main lowering line, one each for the intermediate lead lines, and one operating the sounding machine. If fewer men are employed the time taken to lower and set the sweep at the beginning of each drift will very probably be longer than the surveyor would wish, and may make it necessary to allow an excessively long run up if the tidal stream is at all strong.

When the sweep is set the Lucas machine operator must keep sufficient tension in the sweep wire to ensure that it does not sag between the various points of support;

but he must not apply so much that the two end sinkers are pulled inwards appreciably, for this will make the sweep run shallower than the lowering lines indicate. Good judgement and experience are needed to maintain the correct tension; if there is any doubt it will be safer to apply too little rather than too much.

If the sweep fouls the Lucas machine operator will almost certainly be the first man to notice it. A severe foul will pull the sweep wire off the machine in no uncertain fashion, and may well make it prudent to slip from the quarterdeck position before the wire parts. A gentle foul may feel very like the plucking of a fish at a fisherman's bait; the wire may not render at all as it rides over a smooth obstruction. The two leadlines closest to the part of the sweep wire which fouls will nearly always grow away from the ship more than their outside neighbours, and will give the surveyor a good indication of the position of the obstruction.

A drift sweep of this type, used carefully and intelligently, will determine the least depth over a wreck or obstruction to within half a foot.

(ii) Equipment and rig in a boat. Figure 4–16 shows a sounding boat rigged for sweeping. The width of the sweep has been increased from 30 feet (the length of the boat) to over 50 feet, by passing the lowering lines through blocks attached to the ends of the spars. Ordinary wire hearted leadlines may be used for the lowering lines; they should be marked so that they indicate the depth of the sweep directly. The stray lines make it possible to haul the sinkers into the boat without disturbing the lowering line blocks or the spars; they must be kept reasonably taut when they are not in use, or they may foul the rest of the gear. The steadying bars are about two feet long, and are welded or bolted to the sinkers; provided the sweep wire is kept reasonably taut at all times, these bars will prevent the sinkers from spinning and wrapping it round the lowering lines. The sweep wire usually consists of paino wire, wound on a Lucas sounding machine. Spun yarn might well be used instead, and nylon line would also be very suitable.

The boat's sweep is a smaller and simpler version of the ship's sweep described in (i) above. It is handled in much the same way. Its main drawback when compared with the ship's sweep is its lack of width. With individual swept paths only 50 or 60 feet wide the fixing must be very sensitive, and the management of the various drifts very precise, if reliable results are to be obtained reasonably quickly.

It is recommended that a single boat's sweep should never be used if a ship's sweep or two boat sweep can be used instead. It is most likely to come into its own in very restricted waters, where the position of an obstruction is known accurately. It has also been used on occasions to carry out a clearance sweep alongside a jetty or wharf; in this case, and where there is no convenient tidal stream, the sweeping boat may be towed very slowly along the jetty, in such a way that the sweep always remains at right angles to it. It may well then be necessary to allow for a slight lift in the sinkers, since the sweep will be moving slowly through the water.

(iii) Drift sweeping with a floating boom. It is possible to replace the boat and spars described in (ii) above, and illustrated in Fig. 4–16, by a rigid floating boom. Such a boom might well be made up to any convenient length by bolting together short lengths of flanged pipe. It could be towed into position by boat, and allowed to drift on the tide over an obstruction.

The main drawback of a floating boom is the fact that it cannot carry a surveyor and his assistants. The setting and adjustment of the lowering lines will not be so easy as it is in a ship or boat. More important perhaps will be the difficulties of fixing the boom from the attendant boat, and detecting fouls. Since all the equipment except the boom itself is underwater and invisible, a gentle foul may well pass undetected unless the surveyor is very vigilant indeed.

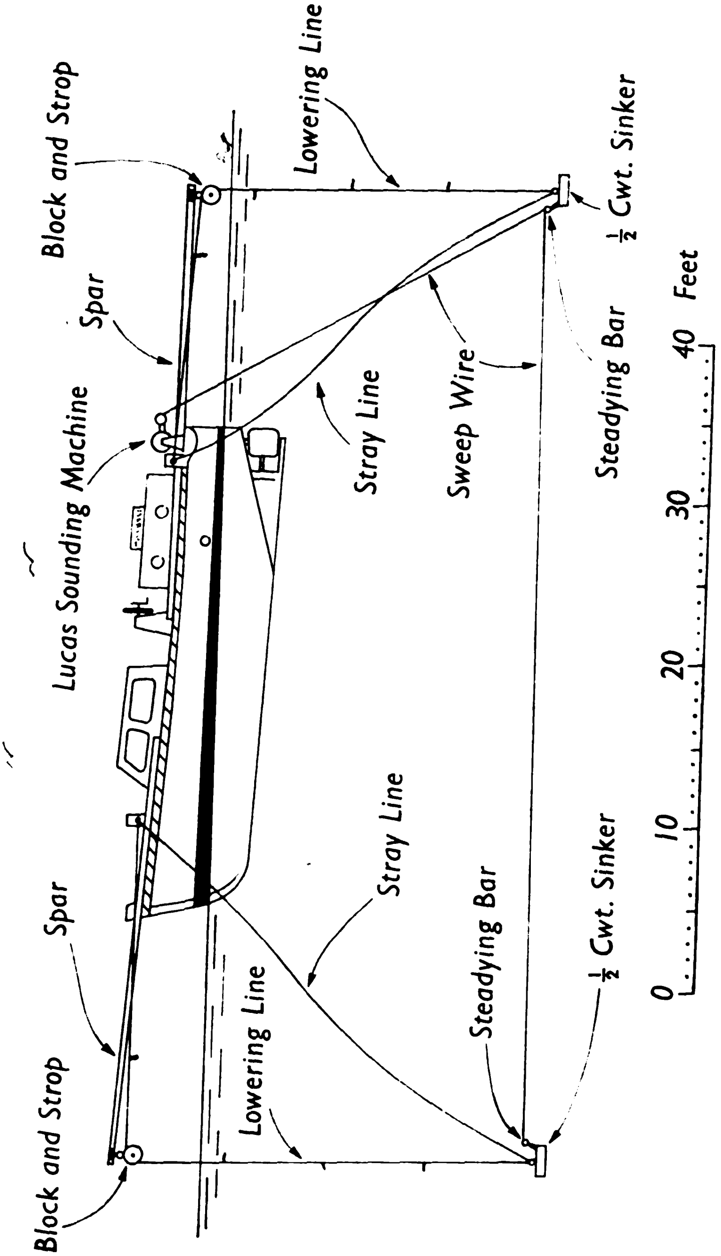


Fig. 4-16

b. Management of a drift sweep in a single vessel

Throughout this section it will be assumed:

(i) That the surveyor knows exactly where the wreck or obstruction is.

(ii) That he can fix himself relative to it with an accuracy of ±5 or 10 feet.

(iii) That he is using his ship and the gear described in section **13a(i)** above to carry out the sweep.

(iv) That he wishes his sweep to be a pure drift sweep (i.e. his vessel must be stopped in the water), and as precise and reliable as he can make it.

(v) That there is a reasonable tidal stream.

(i) Choosing the best time to sweep: wind and tide. Drift sweeping operations cannot be carried out efficiently on every day of the week. The surveyor who knows what conditions to wait for, and keeps his plan flexible so that he can seize his opportunity quickly when it arrives, is likely to complete his drift sweeping task quickly and without bother. The man who rushes blindly on, regardless of the weather and tide, may well become thoroughly frustrated without achieving much useful work.

Ideal conditions for drift sweeping are set out below, with comments on how far actual conditions may be allowed to depart from the ideal, and still be acceptable.

(*a*) The weather should be calm, with no wind or sea. As the sea rises it will become more difficult to set the various lowering lines; the ship may well start to heave, particularly if there is a swell. Common sense must be used to indicate when the time has come to call a halt to sweeping operations; if the lowering lines cannot be set with certainty to within three inches the surveyor should start to think seriously about this point. As the wind rises the ship will begin to drift through the water, and the lowering lines will no longer hang vertically. Again common sense must be used to decide what may be accepted and what may not. The actual depth of the sweep will be a little greater than the indicated depth multiplied by the cosine of the angle that the lowering lines make with the vertical. An angle of 5° should cause no worry, but one of 10° might well be unacceptable. If the surveyor makes no allowance for this his sweep will always be running shallower than he thinks. Most ships, when they are stopped in the water, take up a position with the wind on the beam or the quarter. This fact may make it very difficult sometimes to hold the ship's head in a direction at right angles to that of the tidal stream, and may make sweeping unprofitable in otherwise ideal conditions. If there is any wind, then preferably it should be blowing directly with or against the tidal stream; the worst possible circumstances will occur when a strong wind is blowing at right angles to the tidal stream. Clearly the less windage a ship has the better.

(*b*) The ideal tidal stream would flow in a steady direction for the whole of a flood or ebb period. The worst possible conditions occur when the tidal stream is rotary, and each drift must be made in a different direction. The surveyor should always time his sweeping operations to make the best use of the tidal stream. On occasions it may well be prudent to sweep for only a short time each day, for instance, whilst a semi-rotary stream is setting in roughly the same direction for an hour or two. The strength of the stream does not affect the accuracy of the work, but it may well influence the time that it takes to complete a particular task; when there is plenty of sea room the stronger it is the better; in restricted waters a gentle stream would be more acceptable; a rate of between one and two knots will generally be reasonable.

(ii) Finding the least water over the wreck; tidal reductions. Figure 4–17 shows the first three sweeps carried out whilst finding the least water over a wreck. In practice all the plots would be made in pencil on the same sounding board; they are shown separately here for the sake of clarity. Fixes might well be obtained with sextants to shore marks or very tightly moored dan buoys, or with a suitable electronic device such as Hi-Fix or Hydrodist. In this case the surveyor knows the position of the wreck accurately. His instructions tell him that it is reputed to be clear at 34 feet below chart datum. He has laid a dan buoy with a pellet tail some 1,400 feet up tide of the wreck, to give himself a good mark from which to start his various sweeps. He has prepared the sweeping gear shown in Fig. 4–15; it is rigged on the port side of the ship. He has measured the distances from his fixing position on the bridge to the extremities of the sweep, which has a total width of 300 feet.

Arrangements have been made to report the height of the tide on a nearby tide pole by radio, at 15 minute intervals. The surveyor may therefore set his sweep in the knowledge that he is making the correct allowance for tide the whole time. If current tidal information is not available, it will be necessary to work with tidal predictions, and make corrections later if necessary, when the actual tidal observations have been received on board.

When starting a sweeping operation of this sort, it is essential to establish contact with the wreck as soon as possible, by fouling it with the sweep wire. Until he has done this the surveyor will have no certain knowledge that he is in fact sweeping in the right place.

Therefore, although the wreck in this case is reputed to be clear at 34 feet, he decides to set his first sweep at 37 feet below chart datum. The height of tide is five feet, so the lowering lines will be set to 42 feet.

Referring to Fig. 4–17(*a*), the ship is stopped as shown at fix *a*, nicely down tide from the dan buoy, and instructions are given to lower the sweep to 42 feet. Whilst this is being done check fixes are obtained at *b*, *c* and *d*, to make certain that the drift is in the right direction. Very gentle engine movements may be made as necessary; in many vessels a few revolutions of a propellor will be quite sufficient to move her the very short distances required; the secrets of good control are anticipation and gentleness. At fix 1 the sweep is set; the details of the fix, the ship's head, and sweep setting must all be recorded in the deck book. The echo sounder should be switched on, and kept running throughout the sweeping operations. To start with, and if in doubt, fixes should be obtained fairly frequently; as experience is gained they may be opened out, but never beyond two minutes or one ship's length.

In this case things proceed smoothly and well between fix 1 and fix 6. A very gentle engine movement astern is made at fix 3 to correct an unwanted drift, and the sweep is raised to 41 feet at fix 6, to allow for a changing tidal reduction. Just before fix 7 is due the sweep fouls in no uncertain manner, and then parts. The surveyor obtains his fix, and estimates the foul to be roughly amidships, in the position shown in the diagram. He notes that the echo sounder trace shows no record of the wreck at all; therefore, since the transducers are positioned slightly forward of the bridge, the wreck probably does not extend very far from the foul in that direction. Contact has been established, and the surveyor proceeds back upstream to the dan buoy well pleased.

It is now necessary to decide at what depth to set the next sweep. The object must be to choose a setting which will clear the wreck; it will always be better to raise the the sweep too much if there is any doubt.*

In this case the surveyor decides that a setting of 29 feet should clear the wreck. Since the tide has by now fallen to three feet, the lowering lines are adjusted to 32 feet, and all is ready and set by the time the ship reaches fix 8 in Fig. 4–17(*b*). Note that the check fixes are not shown here, although they have been taken whilst the sweep was being lowered and set. Everything proceeds smoothly; the wreck shows on the echo trace soon after 13 fix, and the sweep runs clear as far as 15 fix, where it is raised.

The surveyor now knows that the least water over the wreck is something between 37 and 29 feet. He therefore proceeds back to the dan buoy and makes his third drift with the sweep set to 33 feet, half-way between the two previous settings. Figure 4–17(*c*) shows the plot of this third run. It can be seen that the ship took a sheer to

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* In one case a wreck reputed to be clear at 36 feet was swept at 36 feet, and was foul. The sweep was then raised in 2 foot steps to 30 feet; all were foul. It was then raised 12 feet to 18 feet, and was still foul. It finally cleared at 17 feet. Much time was wasted by failing to adopt the procedure set out here.

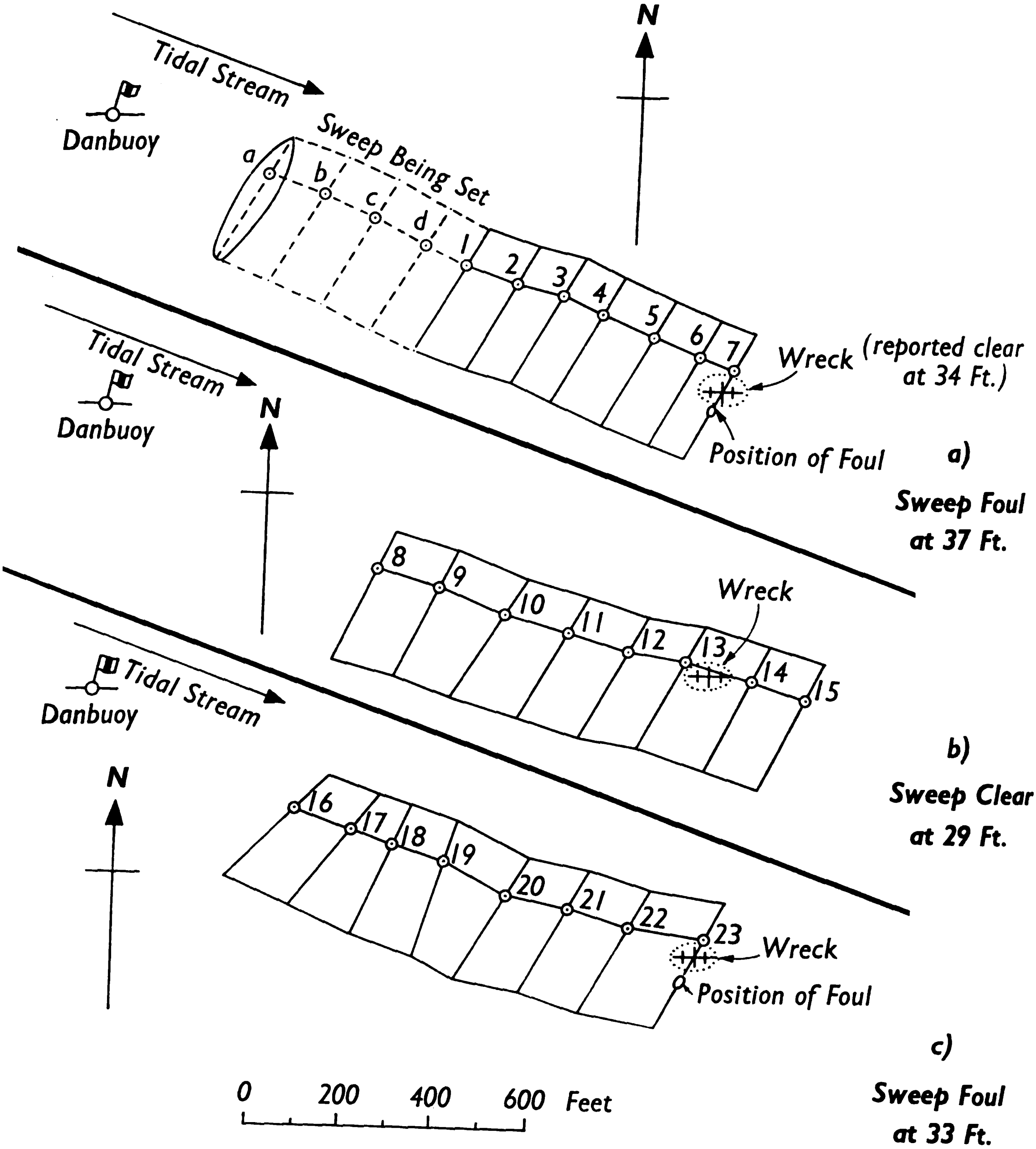


Fig. 4–17

port soon after 17 fix, which was not corrected until 20 fix. Having obtained 22 fix the surveyor, who by this time had noticed two natural transits which defined the position of the wreck, waited for the hoped for foul to occur before taking 23 fix. Sure enough a gentle foul took place at about the right moment, the fix was obtained, and the sweep rode over the obstruction without parting.

These first three drifts have provided the following information:

(i) The sweep is foul at 33 feet.

(ii) It is clear at 29 feet.

(iii) It would probably clear at a depth only a little less than 33 feet, since the foul in Fig. 4–17(*c*) was gentle.

For the next drift the sweep must be set at 31 feet. If it fouls the following sweep should be at 30 feet; if it clears its successor should be at 32 feet.

In this case it clears, and the following sweep (set at 32 feet) clears also. The plots for these sweeps are not illustrated, but they would be similar to those shown on Fig. 4–17.

Thus, by carrying out five drifts, the surveyor has established the fact that the wreck is foul at 33 feet, and clear at 32 feet. Had the second drift (at 29 feet) been foul, it would have been prudent to go on raising the sweep in steps of eight feet or more, until it cleared.

The next task must be to clear an area round the wreck, to make quite sure that nothing shallower than 32 feet can exist.

(iii) Clearing an area round the wreck. Before commencing the clearing sweeps it will be prudent to ink in on the sweeping board the relevant information which has been obtained so far, and clean it up generally. In Fig. 4–18 the area delineated by the firm black lines has been cleared at 33 feet; it is of course the area swept between fixes 16 and 23 on Fig. 4–17(*c*). The area inside the pecked black lines is part of the the last sweep referred to in (ii) above, which ran clear at 32 feet.

The two drifts shown with fix numbers in the figure were made with the sweep set at 32 feet; both ran quite clear. Note the overlaps between the various drifts, which are reasonable for work being carried out on this scale. Note too that a gap in the work exists between fixes 41 and 44; it is shown hatched. This gap is typical of the sort of thing that can happen, even in the best managed vessels. It must be covered by running another drift, with the sweep set at 32 feet.

When this has been done the surveyor will know that no obstructions with a depth of less than 32 feet over them can exist within the area cleared. In most cases it will

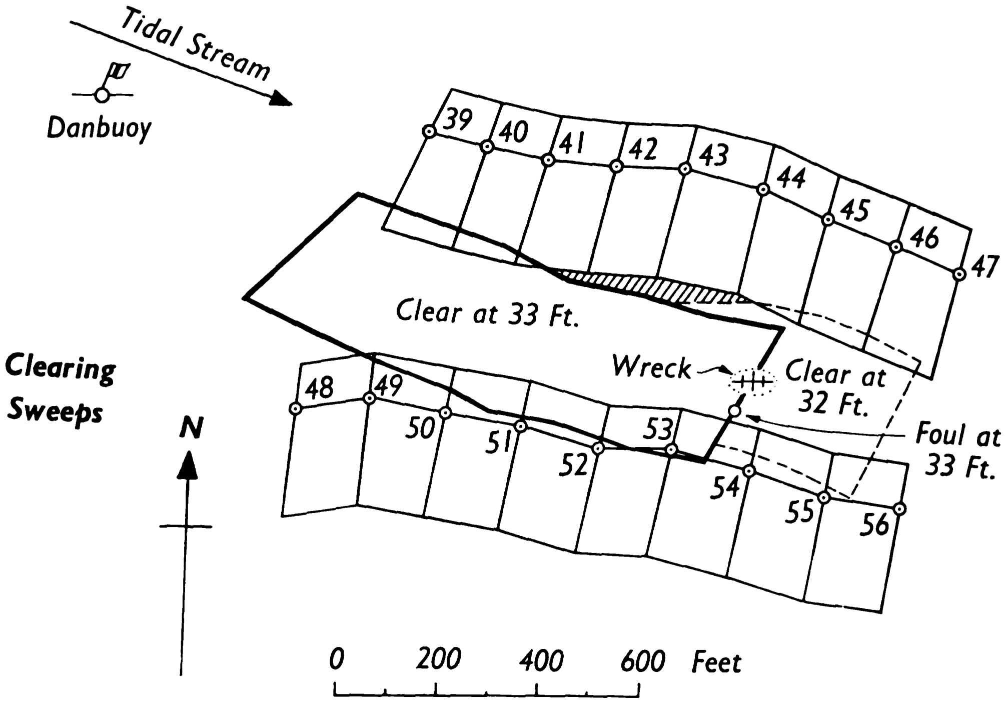


Fig. 4–18

be sufficient to clear an area of the size shown in Fig. 4–18. However, it is not possible to lay down definite rules, and the surveyor must always be guided by prudence and common sense.

(iv) The sweeping tracing. Figure 4–19 shows the final sweeping tracing, which forms the permanent record of the work. Note that the 'wreck' is no longer shown in its original reported position. The absolute position of the foul must be given, both on the tracing and in the accompanying sweeping report, which must also include the following information:

(i) How the sweeping was controlled, with full details of any corrections applied to the observed values of the fixes, if an electronic fixing aid was used.

(ii) How the tidal reductions were obtained and applied.

(v) Use of a diver. It should never be forgotten that in suitable circumstances, e.g. with clear water and gentle tidal streams, the best way to find the least water over a wreck or obstruction may well be to use a diver. If he is a surveyor and can use an aqualung or similar lightweight breathing apparatus, so much the better. The use of divers is discussed in *Part* 4 of this chapter.

14. Drift and Drag Sweeping between two Vessels

When the vessels available to the surveyor are themselves small, or where the searoom is restricted, it may be attractive to carry out a drift or drag sweep between two craft, rather than have resort to the single vessel sweeps referred to in Section 13 above. Two boats drift sweeping can, in good conditions, cover more ground in a given time than the single ship depicted in Fig. 4–15; in particular they will be able to manoeuvre far more easily than the ship. If these were the only considerations this method would be inherently more attractive than that described in Section 13. However, it has certain disadvantages which the prudent surveyor should consider carefully before deciding to use it. These, together with the best known ways of overcoming them, are set out below.

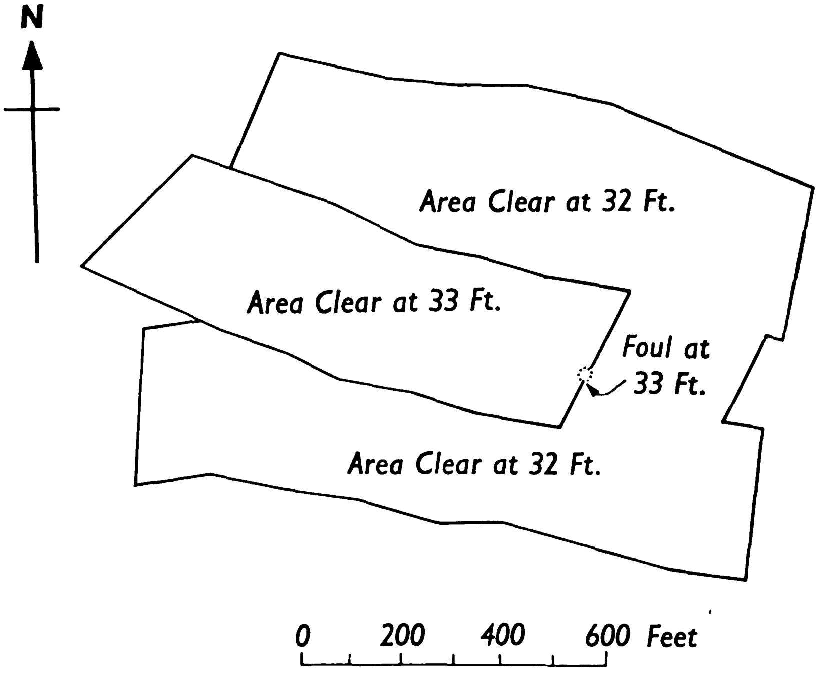


Fig. 4–19

a. Basic equipment and rigging

Figure 4–20 shows two sounding boats fitted with the basic equipment that is required for drift or drag sweeping.

Each boat is fitted with a small hand winch which carries about 150 feet of light strong lowering line (3½ m.m. diameter oceanographical winch wire is very suitable). In the surveying service of the Royal Navy these winches are modified versions of the 400 fathom Lucas sounding machine. Each lowering line is marked every foot in the manner of a leadline.

In the control boat the lowering line passes over a block at the gallows head, and then down to the streamlined sinker, to which it is shackled directly. The heavier this sinker can be (within reason) the better; the controlling factor is generally the safe working load of the gallows, and a weight of about 100 lbs. is reasonable. A wire pendant, fitted with a swivel and an Inglefield clip, is also shackled to the lifting ring of the control boat's sinker. In due course, when the sweep is passed, this Inglefield clip will be mated with its twin on the end of the sweep wire.

The wing boat's lowering line passes over a block at the gallows head, and then down to the Hatfield swivel, which is itself shackled to the sinker. This swivel, which contains a ball thrust bearing packed in grease, enables the sinker to rotate freely, without wrapping the sweep wire round the lowering line. If this happened it would not be possible to heave in or pay out on the sweep wire as the distance between the two boats altered, and the wire might either become very slack, or part. Note that a Hatfield swivel is not needed at the control boat end, since no harm can come if the wire pendant takes a few turns round the lowering line.

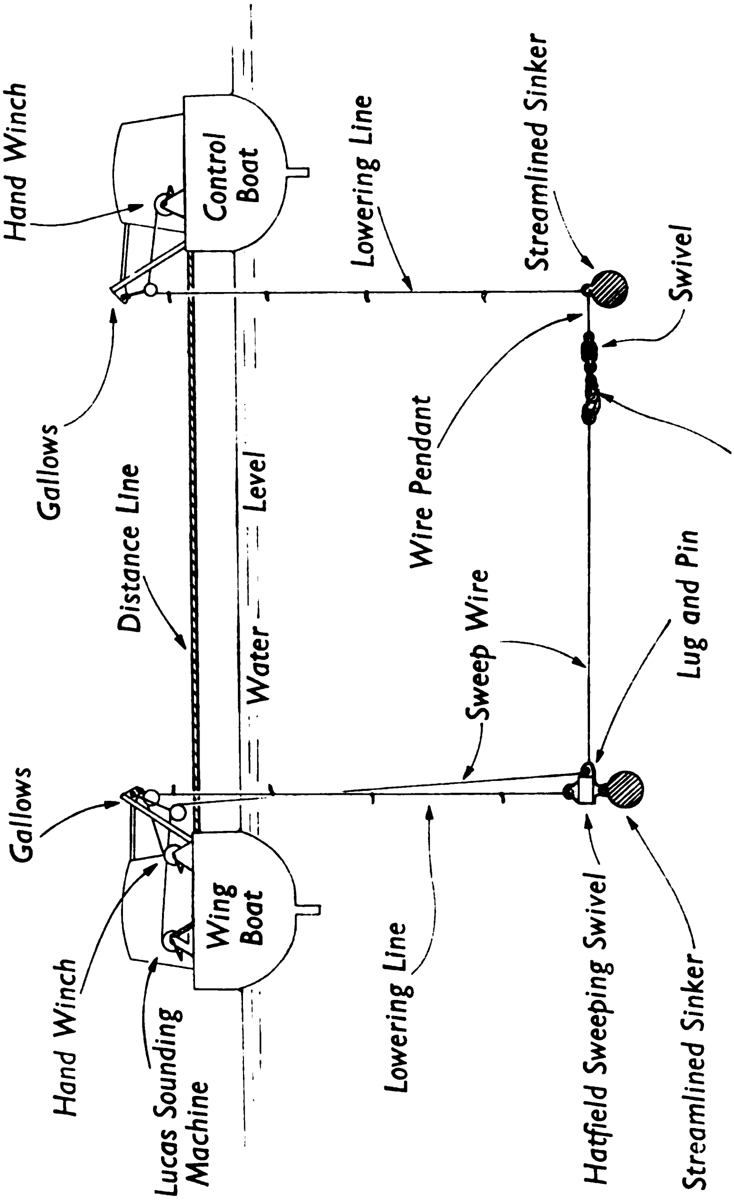
The sweep wire is carried on a 400 fathom Lucas sounding machine fitted in the wing boat. This machine must be carefully positioned so that its operator, who is one of the most important persons connected with the sweep, is as comfortable as possible and can see both the lowering line and sweep wire entering the water. The wire passes through a block on the gallows head, which must not foul the lowering line block, down through the lug in the Hatfield swivel, where it is retained by a pin, and across to the control boat, where an Inglefield clip fitted to its end is snatched into the control boat's clip. The pin in the lug of the Hatfield swivel must be hardened, to resist the chafe of the sweep wire, which otherwise will bite into it quite quickly. Taut wire still seems (in 1968) to be the best material for the sweep wire. It is not ideal, since it tends to sag. However tests carried out with monofilament nylon (which stretches too much) and braided terylene (which does not stretch but is not strong enough) indicate that these possible substitutes are not suitable.

The winches, sounding machines, and blocks must be positioned in the boats so that the lowering lines and the sweep wire lead fairly through the various blocks. Any misalignment will cause chafe, which must be prevented.

If the equipment is fitted in vessels larger than boats, the extra space available will make its operation more convenient. Power winches could well be used for the lowering lines, and the larger 1,000 fathom Lucas sounding machine might be used to hold the sweep wire.

The two boats must (in theory) be held at a constant, and known distance apart, whilst the sweep is being run. This may be done by observing the distance between them by rangefinder or sextant and 10 foot pole, and adjusting the position of the wing boat as necessary; or better still by using the distance line shown in the diagram. This line may be made of light wire, or grass (which will float); it should be attached to the pivoting points of the boats, and be kept nicely taut by the coxswain of the wing boat.

Note that the handling of the sweep wire and the station keeping are both attended to in the wing boat, which will carry the surveyor's assistant. This leaves the control boat comparatively unencumbered, and the surveyor himself free to devote his full



Two Boat Sweep

Basic Equipment and Rigging

Fig. 4–20

attention to his primary duty, which is the handling and fixing of the sweep relative to the obstruction which is being swept. But it requires first class communications and a capable assistant if it is to work well. Some surveyors may prefer to handle the sweep wire from their own control boat; there is nothing against this practice except the fact that it will tend to concentrate most of the work in one boat, perhaps overloading the surveyor himself and leaving his assistant with little or no responsibility.

It is essential that the men in the two boats, when working the rig shown in Fig. 4–20, should be able to communicate with each other easily and with certainty, over ranges of up to 150 yards. Electronic loud hailers and radio sets may both be used for this purpose. The human voice is not likely to be powerful enough, even when aided by a megaphone. Many of the routine messages can be passed, with advantage, by visual signals.

b. Using the equipment; what the surveyor needs to know; difficulties and snags

The equipment and rigging shown in Fig. 4–20, and described in **a** above is all very good in theory. The two boats are keeping perfect station, and move together as one unit; the lowering lines hang vertically in the water; the sweep wire is quite taut, and runs horizontally between the two sinkers at a known depth.

In practice none of these things is likely to happen. The wing boat will never be able to maintain perfect station, however much care is taken. Its movements towards and away from the control boat will mean that the sweep wire sounding machine operator will constantly have to heave in or pay out to maintain a steady tension in the wire. A varying tension, and movements in relative bearing of the two boats, will affect the behaviour of the underwater parts of the sweep wire. The lowering lines will only hang vertically if both boats are stopped in the water and there is no tension at all in the sweep wire. As soon as tension is applied to the wire the sinkers will be pulled together slightly. As soon as a boat moves through the water (to maintain station for instance) its lowering line will bow out; it will be neither straight nor hanging vertically. If the surface tidal stream is not the same as that experienced by the sinkers (and it may not be) then the lowering lines will not hang vertically even if the boats are stopped in the water, and there is no tension in the sweep wire. The part of the sweep wire between the two sinkers must sag slightly, however taut it is, since it is heavier than water; neutrally buoyant material would behave better. Whatever material is used the wire will bow out astern as soon as either boat moves through the water; it may or may not then lift or sag as well.

All these factors combined to complicate the practical use of the basic equipment described in **a** above. In order to solve the problems which confront him, the surveyor must first of all decide exactly what he needs to know. It will always be necessary to have reliable information concerning the following points:

(i) *The depth of the sinkers*

The best way to find this out will be to measure it directly, and not rely on the markings on the lowering lines, which will almost certainly be hanging out of the vertical plane. Depth may be measured 'directly' by echo sounder or pressure gauge, provided these have been properly calibrated.

(ii) *The tension in the sweep wire*

This must be kept as constant as possible. If the tension is allowed to vary then the depth of the sinkers, and the sag of the sweep wire between the sinkers will vary also. The best method is to use the Owen automatic tensioning winch, which has just been developed (in 1968). If a winch is not available, then a spring balance may be inserted between the gallows head and the sweep wire lead block in the wing boat in Fig. 4–20, and used by the Lucas machine operator to maintain a steady tension. Reports from sea indicate that the new Owen winch is so much better than the old equipment that it has become essential to use it if the sweeping is to be of the highest possible quality.

(iii) *The sag in the sweep wire between the sinkers*

At the present time (1968) this is the most intractable of the problems connected with drift and drag sweeping between two vessels. If a drift sweep is used the sag will vary inversely with the tension in the sweep wire, and directly as the distance between the boats. It may be measured by carrying out a calibration with a dip stick (see Section **8c** of this chapter). If it is neglected, and the surveyor assumes that the sweep wire is horizontal throughout its length, then he will always tend to be sweeping at a depth slightly greater than he thinks.

As soon as one or both of the sweeping vessels start to move through the water, the sweep wire will bow out astern, and the static sag referred to above will change. Trials indicate that almost anything can happen. The wire can, in certain circumstances, lift, and put the surveyor in the dangerous position of thinking that he is sweeping deeper than in fact he is.

Until devices can be supplied that will measure directly the depth of the sweep wire at various points along its length, two golden rules must be applied by the surveyor who wishes his sweep to be of the highest possible quality.

They are:

(*a*) **Do not allow the distance between the vessels to become too great, and**

(*b*) **At all costs prevent the vessels from moving through the water whilst the sweep is being carried out. Drag sweeping is thus automatically precluded.**

If a lower standard of depth keeping accuracy can be accepted (for instance, when a simple clearance sweep is being made) then these rules may be relaxed; but the surveyor must, as always, be guided by prudence and common sense.

c. Measuring the depth of the sinkers; echo sounders; depth gauges; angle of sweep measuring devices

(i) Using echo sounders. Several small portable echo sounders are available to the surveyor in 1968. If the transducers of a pair of these are secured to the top of each of the sinkers in Fig. 4–20, in such a way that they look upwards, echoes will be received from the surface of the water, and the depth of the sinkers may be indicated directly on recorders carried in the boats. Each unit must be carefully calibrated from time to time to ensure that transmission line and speed errors are properly allowed for. A graph may be prepared in each boat connecting apparent depth by echo sounder against 'true' depth, over the range of depths which will be used whilst sweeping; there will be no need to adjust the machines to indicate true depth directly. When calibrating, 'true' depth will be obtained from the markings on the lowering lines, and the surveyor must ensure that these are in fact up and down throughout their whole length (see **b** above).

(ii) Using depth gauges. The pressure exerted by a column of sea water one foot high is about 0·446 lbs./in^2; conversely a pressure of 1 lb./in^2 will be experienced at a depth of about 2·24 feet. This principle may be applied to the measurement of the depth of a sweeping sinker in the following way:

(*a*) A bladder, about the size of an ordinary football bladder, is attached to the sinker, and connected to a pressure gauge via long length of thick walled flexible tubing, which must resist the pressure of water at the sweeping depth.

(*b*) The bladder, tubing, and gauge are pressurised to a few pounds per square inch, and the bladder is then lowered over the side, attached to the sinker.

(*c*) As soon as the water pressure at the bladder exceeds the initial pressure applied to the system, the gauge needle will start to move; provided that the flexible connecting tube does not become crushed the gauge will indicate the water pressure at the bladder, and this may be converted to the depth of the sinker.

(*d*) Each unit must be calibrated in the field just before it is used, and at regular intervals during use, by drawing a graph of indicated pressure against true depth. Observations must be obtained whilst the sinker is being raised and lowered.

Trials at sea indicate that it is simple and quick to make this graph, and that its use enables the surveyor to detect changes in depth of six inches quite easily. All the equipment may be assembled on board from materials which are normally used for other purposes.

The following points should be noted:

(i) The greater the volume of the bladder, and the smaller the internal bore of the flexible tube, the better. However, the bladder must not be too big, or it will decrease the 'weight' of the sinker, and increase drag. An ordinary football bladder has been used successfully, and is certainly quite large enough. There is no reason why the bladder should not be housed in a recess within the sinker. If the flexible tube is strong enough to serve as the lowering line as well, so much the better.

(ii) The pressure gauge will not start to measure depth until the external water pressure at the bladder exceeds the initial pressure of the system. For this reason the bladder should not be inflated too much to start with, particularly if it is to be used at shallow settings. For greater working depths more pressure may be used to start with, or it may be applied to the system as the bladder is lowered. At great depths the system will continue to operate until the quantity of air in the bladder has been compressed to a negligible volume.

(iii) The criterion for correct operation of the system will always be the calibration in the field. If at the working depths the pressure depth relationship referred to above is confirmed on the calibration graph, then the system is working properly. This relationship is, of course, neither exact nor permanent; it will vary with the qualities of the sea water concerned, and slightly with temperature. Changes in barometric pressure will have no effect.

(iv) Small air leaks in the system will not harm its working in any way, until sufficient air has been lost to bring about the complete collapse of the bladder.

(v) If the walls of the flexible tube are not strong enough to resist the water pressure at the working depths, then the effective point of measurement will no longer be at the bladder; furthermore, it will change with depth. This will not matter provided that the calibration referred to above is carried out; the straight line graph which connected depth and pressure when the tube was pressure resistant will now become a curve.

(iii) Using an angle of sweep measuring device. If the angle at which the lowering line enters the water is measured, and if it is assumed that the lowering line remains straight throughout its length, then the depth of the sinker may be obtained from the expression

Depth = Amount of lowering line below water line × Cos θ,

where θ = The angle between the lowering line and the vertical, commonly known as the angle of sweep.

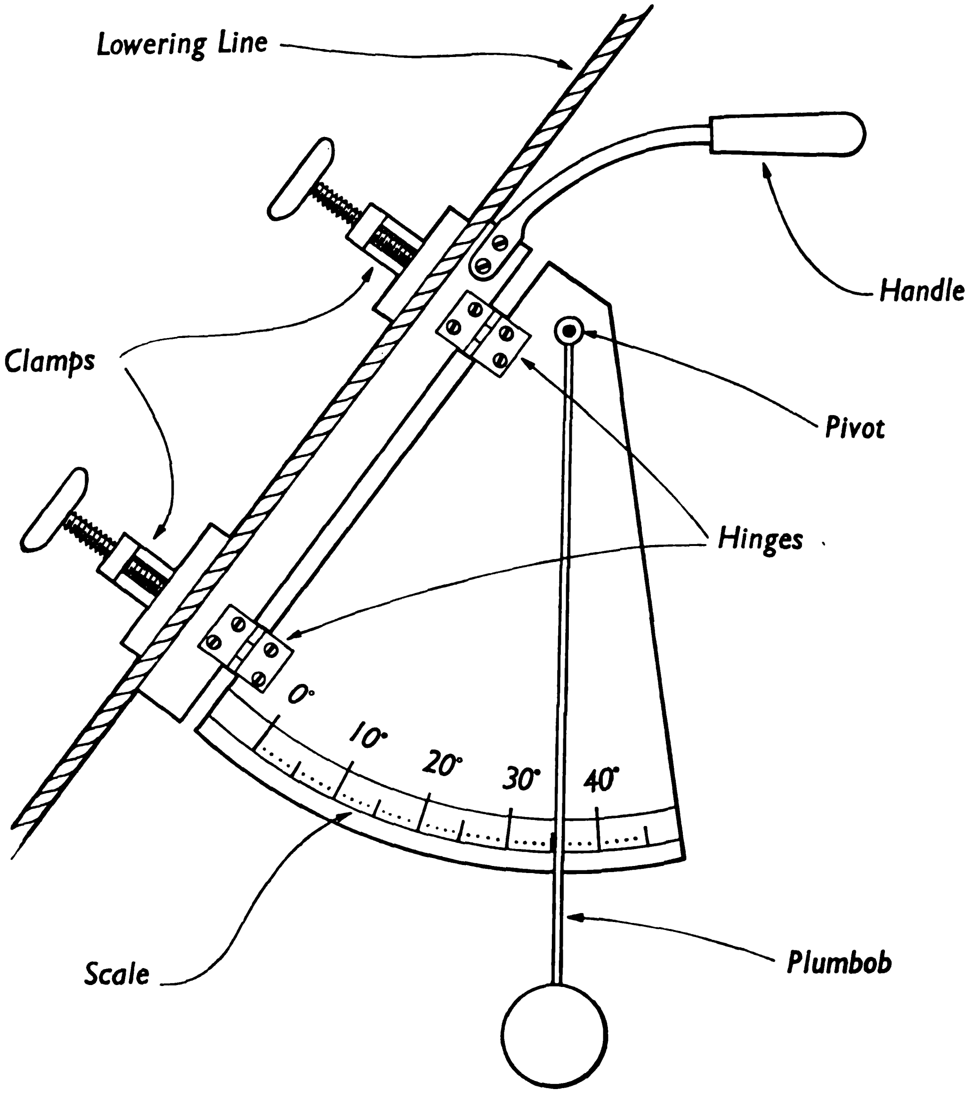
It is fairly easy to measure the angle of sweep, but very difficult to determine what shape the lowering line takes below the surface of the water. In most cases the angle of sweep measured at the surface will be greater than the average angle throughout the length of the lowering line, and the sinker will in fact be running deeper than the surveyor thinks. Thus any errors will be on the safe side. However, it would not be impossible for a sub-surface angle of sweep to be greater than that measured at the surface, and for the sinker to be running shallower than the surveyor thought, particularly with inexperienced crews working in a tideway.

For these reasons this method should not be used if either of the methods described in **(i)** and **(ii)** above can be used instead. If it is used, then the surveyor would be wise not to place too much reliance on the results of his work.

The angle of sweep may be measured in one of the following ways:

(*a*) ***With a large protractor.*** If a large protractor is held against the lowering line, and aligned on the horizon, the angle of sweep may be read off directly. Care must be taken to hold the protractor in the vertical plane which contains the sweep wire.

(*b*) ***With a clinometer.*** Figure 4–21 shows a simple angle of sweep clinometer, which may be made on board. It may be held against the lowering line, or clamped to the line if no depth setting adjustments are likely to be made. Free movement at the hinges will ensure that the angle of sweep is measured in the vertical



Angle of Sweep Clinometer

Fig. 4–21

plane, even though the instrument may be held or clamped to the lowering line slightly askew.

d. Maintaining a steady tension in the sweep wire; the Owen automatic tensioning winch

If the sag in the sweep wire is to remain constant, then the tension in the wire must be kept steady, in spite of the possible relative movement between the boats. It has been found in practice that a tension of between 15 and 20 lbs. is reasonable; the higher value should be used provided the sinkers are heavy enough not to be pulled together too much by it. A steady tension may be maintained in one of the three following ways:

(*a*) By using an Owen automatic tensioning winch. This method is by far the best.

(*b*) By keeping a constant reading on a spring balance placed in the lead of the sweep wire.

(*c*) By feel and eye. This method may sound easy and attractive, but it is most unreliable and should never be used except as a last resort.

(i) The Owen automatic tensioning winch. This winch may be used instead of the Lucas sounding machine, shown in the wing boat in Fig. 4–20. A drum, which carries the sweep wire, is driven by a constant speed electric motor through a simple 'fluid flywheel' clutch, which is partly filled with oil. The winch is always trying to heave in on the sweep wire; but if the tension in the wire rise above a certain level, which may be pre-set by varying the amount of oil in the clutch, the clutch will slip and pay out the wire until the tension falls to the required level. In practice the clutch is slipping most of the time, maintaining a steady tension.* If, for any reason, the tension varies, then the winch heaves in or veers immediately, and restores it to its original value.

When the sweep is being passed the tension in the sweep wire can be reduced temporarily by reducing the speed of the electric motor which drives the winch. Once the sweep wire has been passed, the winch will look after it automatically for hours on end.

Its use cannot be too highly recommended.

(ii) Use of a spring balance to maintain constant tension. If an Owen winch is not available, then the Lucas machine in the wing boat in Fig. 4–20 must be operated by hand. If a spring balance is inserted between the gallows head and the sweep wire lead block, its reading will be proportional to the tension in the sweep wire.

Referring to Fig. 4–22, which shows the rig of this equipment,

$$p = w \cos \varphi = 2t \cos \tfrac{1}{2}\theta,$$

where p = The reading of the spring balance,
w = The weight of the lead block,
φ = The angle between the vertical and the lie of the lead block,
t = The tension in the sweep wire,
and θ = The angle between the two parts of the sweep wire.

Therefore $p = 2t \cos \frac{1}{2}\theta + w \cos \varphi$

and $$t = \frac{p - w \cos \varphi.}{2 \cos \frac{1}{2}\theta}$$

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* The clutch really produces a steady torque; this will produce a steady tension in the wire only if the working diameter of the winch drum remains constant. A long and fairly large diameter barrel is therefore used.

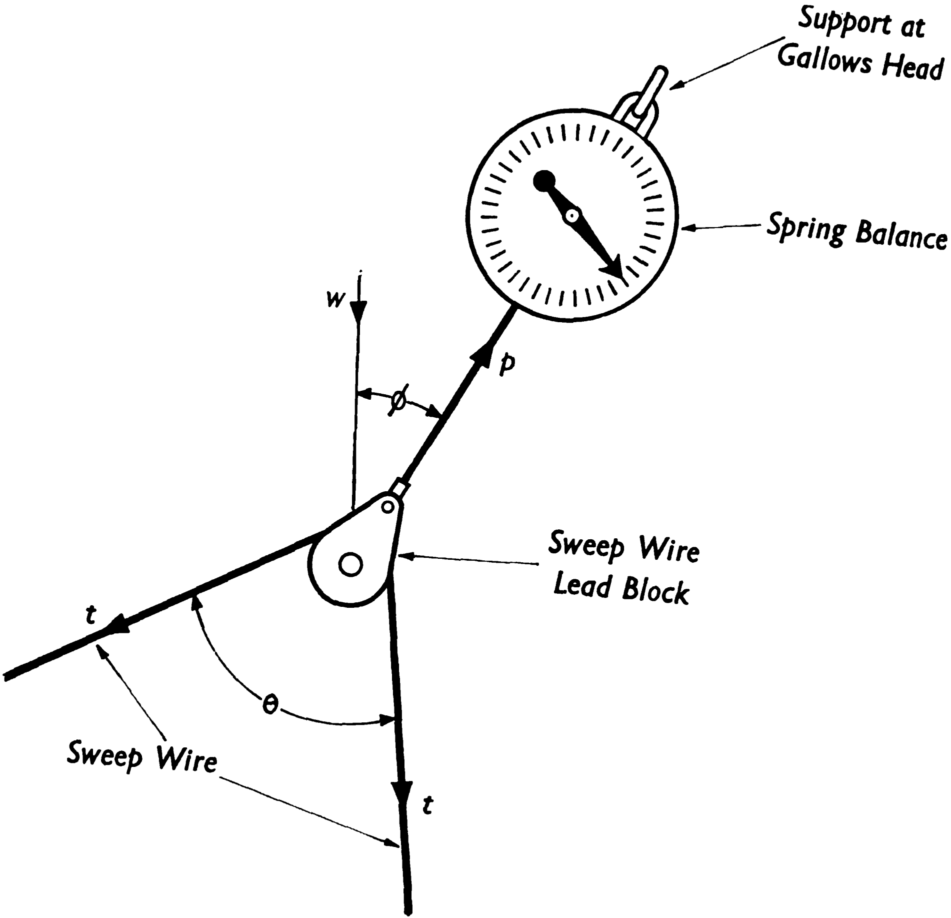

Fig. 4–22

Suppose that $t = 20$ lbs.

$\theta = 70°$, and $\cos \frac{1}{2}\theta = 0{\cdot}82$

$\varphi = 30°$, and $\cos \varphi = 0{\cdot}87$

and $w = 15$ lbs.

Then $p = 40 \times 0{\cdot}82 + 15 \times 0{\cdot}87$

$= 45{\cdot}8$ lbs.

Thus, in these circumstances, and with a block weighing 15 lbs., a sweep wire tension of 20 lbs. will be produced by adjusting the sweep wire Lucas weighing machine until the spring balance reads just under 46 lbs. Since the important thing in practice is not to achieve an exact and predetermined tension in the wire, but to hold a reasonable (and perhaps unknown) tension quite steady, the formulae above may generally be simplified to the forms given below:

$$p = 1{\cdot}6t + 0{\cdot}9w,$$

and $$t = \frac{p - 0{\cdot}9w.}{1{\cdot}6}$$

Note that this last formula indicates that errors of tension in the wire will be about two-thirds those of the reading of the spring balance.

When sweeping, the Lucas machine operator should not allow the spring balance reading to vary by more than 3 lbs. from the chosen setting. Great concentration, and quick reflexes will be necessary. If the tension is allowed to vary appreciably, then the depth of the sinkers and the sag in the sweep wire will vary too, and the sweep will not be very reliable.

e. Controlling the sag in the sweep wire

The sag of a sweep wire that is not moving through the water will vary directly as the square of its length, and inversely as the applied tension. Trials indicate that a reasonable approximation to it is given by the formula

$$\text{Sag (in feet)} = \frac{\text{Weight of wire per foot} \times (\text{length in feet})^2.}{8\ (\text{Tension in wire in lbs.})}$$

Lucas machine and taut wire both weigh about 0·0025 lbs./foot in air, and about 0·0020 lbs./foot in water. The table below gives the sag in the wire for various tensions and various lengths of sweep wire.

DRIFT SWEEPING—APPROXIMATE VALUES OF SAG

TENSION IN SWEEP WIRE IN LBS.	LENGTH OF SWEEP WIRE AND SAG (BOTH IN FEET)					
	100	200	300	400	500	600
10	0·2	1·0	2·2	4·0	6·2	9·0
15	0·2	0·7	1·5	2·7	4·1	6·0
20	0·1	0·5	1·1	2·0	3·1	4·5
25	0·1	0·4	0·9	1·6	2·5	3.6
30	0·1	0·3	0·7	1.3	2.1	3·0
35	0·1	0·3	0·6	1·1	1·8	2·6
40	0·1	0·2	0·6	1·0	1·6	2·2

Note

(i) That not much is gained by increasing the tension above 20 lbs.

(ii) That the sag increases rapidly as the length of sweep wire increases, and almost doubles itself between 300 and 400 feet.

For these reasons it is recommended that for rigorous drift sweeping the tension in the wire should be set at about 20 lbs., and the length of sweep wire (or distance between the vessels) not allowed to exceed 300 feet.

It must be stressed that these approximate values for the sag in the wire are only valid if the wire is not moving through the water. If a drag sweep is being carried out and the wire is moving through the water, then almost anything can happen. The wire may sag more than the amounts indicated here; even worse, it may lift, and put the surveyor in the dangerous position of thinking that he is sweeping deeper than in fact he is.

f. Management of a drift sweep between two vessels

There is little difference between the management of a drift sweep between two vessels, and that of a drift sweep in a single vessel (see Section **13b** above). Methods of fixing will be the same. The dan buoy or pellet, if used, should be laid slightly across tide from the obstruction to be swept, to allow for the fact that the fixing will take place at one end of the sweep. If the two vessels are boats, they will be less affected by the wind than a ship, and should therefore be able to sweep successfully in less favourable conditions. They will almost certainly be more manoeuvrable than a ship, and should on this account be able to complete a given task more easily and more quickly.

Assuming that the position of the obstruction is known, that the basic rig of the sweep is that shown in Fig. 4–20, and that the surveyor is satisfied concerning all the points discussed already in this section, the procedure for sweeping is as follows:

(i) The two vessels proceed to a point fairly close up tide from the obstruction, which may conveniently be marked by the dan buoy or pellet referred to above. Here they pass the sweep. The control vessel stems the tide, whilst the wing vessel opens out to sweeping distance. Both vessels then set their ends of the sweep wire to the required depth, and the wing vessel checks that the tension is correct when the distance line is taut.

(ii) The control vessel fixes herself, takes a compass bearing into the wing vessel, and, knowing the length of the distance line,* plots the position of the sweep. If all is well the centre of the sweep will be directly up tide from the wreck. Both vessels should now be stemming the tide, and all is ready.

The sweep may be made in one of two ways:

either

(iii) Both vessels turn inwards about 90°, and keep their engines going very gently astern, so that the distance line remains taut whilst the tide carries the sweep down over the obstruction,

or

(iv) Both vessels stop all propellor movements, and drift. They will then be pulled together slowly by the tension in the sweep wire, and the distance line will have to be tended constantly.

Method (iii) is the more convenient of the two, and is especially suited to boats fitted with 'Kitchen' rudders. Method (iv) is usually used with larger vessels, which are not so manoeuvrable as boats. Whichever method is used, great care must be taken at the start of the drift to ensure that the sweep is in fact at the desired depth. As the vessels pass through the transition stage from stemming the tide to drifting with it, the lowering lines will almost certainly have to be tended; to start with the surveyor might well make a practice sweep, clear of the obstruction, to find out the best way to proceed.

(v) If the sweep clears, it may be raised, and the vessels may proceed back to the starting point. In calm weather it will probably be best to lift the sinkers (and the sweep wire) just clear of the water whilst this is being done. If the vessels are rolling the sinkers will behave better if they are kept just below the surface. In any case the sweep wire must always be sighted between sweeps, to make sure that it has not picked up any weed or flotsam.

(vi) If the sweep fouls it will probably clear itself if both vessels turn into the tide immediately and steam ahead. In the last resort it must be cut in the wing vessel.

(vii) When a foul occurs a fix must be obtained immediately. The surveyor should estimate as best he can the distance along the sweep wire to the point of foul, which will always be slightly uptide of the line joining the two vessels, and then check that the position of the point of foul does in fact agree reasonably well with the known position of the obstruction. This is not done in order to check the previous fixing of the obstruction, but to make certain that the right object is being swept. On occasions unwary surveyors have spent many hours sweeping submerged but buoyant moored buoys left close to wrecks by demolition parties, without realising it.

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* Some surveyors prefer to measure this distance with a 10 foot pole or rangefinder.

g. Management of a drag sweep between two vessels

The surveyor should only resort to drag sweeping between two vessels if it is quite impossible to drift sweep, owing to the weakness or absence of a tidal stream.

The control of a drag sweep may well appear to be easier than that of a drift sweep, since the two vessels will be moving through the water the whole time. However, this very movement will affect the shape of the lowering lines and the underwater part of the sweeping wire in a way which will be almost impossible to predict, and very difficult to control.

Drag sweeping is in most respects very similar to drift sweeping, and all the relevant points referred to in **f** above apply. The two boats will, of course, have to replace the motion imparted in a drift sweep by the tidal stream with their own movement through the water. The following additional points should be borne in mind:

(i) The depth of a drag sweep should always be measured 'directly', i.e. by echo sounder or depth gauge, unless this is quite impossible. If an angle of sweep is measured in each craft, particular attention must be paid to station keeping and to maintaining a steady speed of advance; quite small alterations of course or speed in either vessel can cause the sweep to alter its running depth very appreciably.

(ii) The tension in the sweep wire may well be increased (if the gear will stand it) above the 20 lbs. normally used for drift sweeping. Great care must be taken to maintain an even tension in the sweep wire.

The sag or lift of a drag sweep is not very likely to exceed twice the amounts shown in the table in **e** above. Thus with a 400-foot sweep and a tension of 30 lbs., the centre of the sweep will probably be within ±3 feet of the actual depth of the wire at the sinkers.

Drag sweeping comes into its own when it is necessary to carry out a clearance sweep over a fairly large area. If the sweep is set to run six feet deeper than the required sweeping depth, and all the points referred to in this section are attended to, then it is most unlikely that any point of it will ever run shallower than the required sweeping depth.

15. Drag Sweep used by the U.S. Coast and Geodetic Survey

For many years the U.S. Coast and Geodetic Survey has used a wire drag to carry out clearance sweeps similar to those usually made with Oropesa gear by British surveyors, and to locate obstructions and shoals. The standard wire drag consists of a sweep wire which may be anything up to 12,000 feet long, which is supported at intervals from buoys, and towed through the water at a speed of about 1½ knots. Two fairly powerful launches and a smaller tender are required to operate it. The deep wire drag, which is heavier than but otherwise similar to the standard equipment, is used for sweeping at depths greater than 20 fathoms.

Full details concerning both sweeps, and the ways in which they are used, may be found in *The Wire Drag Manual—US Coast and Geodetic Survey Publication No.* 20–1.

Part 4 The Use of Divers for Surveying

16. Introduction

The idea of sending an experienced man down in a diving suit, to examine a wreck, shoal or obstruction, has been an attractive one for very many years. Before the advent of modern self-contained lightweight breathing sets all hydrographic divers had to descend in the standard suit, breathing air pumped down to them from the surface, encumbered by heavy boots and a thick lifeline, and peering out through the small ports of a large helmet. The equipment was so clumsy, and placed so many restrictions on the free movement of the man using it, that it was used only very rarely.

Modern self-contained breathing equipment has transformed the situation. The standard diver, his movements limited by his heavy equipment, now becomes a free swimmer restricted only by his physical limitations and the tenets of prudence. Breathing apparatus can easily be carried in ordinary surveying boats, as a matter of routine. The trained man can, in suitable conditions, be visually examining the highest point of a new found shoal from a range of a few feet minutes after discovering it.

Not all surveyors take naturally to swimming, and only a few relish the role of swimming underwater. Those that do should be encouraged as much as possible, since the free swimming diver who is also a surveyor is a pearl of very great price. He will on occasions be able to complete in an hour or two work which would otherwise take several days; more important, he will be able to provide evidence of identity (of a wreck perhaps) which could otherwise only be obtained by using a television camera. Free swimming divers who are not trained in surveying techniques can be most useful; but their task will always be made easier, and will probably be performed better and more quickly, if a surveyor who is also one of their own company can guide and advise them.

In what follows it is intended to discuss how free swimming divers can help the surveyor in his work. No attempt will be made to lay down any rules for the safe conduct of underwater operations; these can only be made by those responsible for the training of divers, and the surveyor must accept them.

17. The Use of Free Swimming Divers in Surveying

a. Practical requirements and limitations

A diver will always work best when the tidal stream is slack, and will not be able to do much useful work if its rate is more than about half a knot. Diving operations should always, therefore, be carried out over slack water periods. It should be remembered that slack water on the surface does not necessarily mean that there will be no tidal stream at the depth at which the divers will be working.

Good underwater visibility will always be an asset. For some types of work, e.g. examining a shoal of fairly large extent, it will be a necessity. Experience has shown that to be certain of finding the least depth over a shoal in a reasonable time, the underwater visibility distance must be at least half the maximum extent of the top of the shoal. An experienced diver examining a wreck can collect extremely valuable information when the visibility extends to only six feet.

The time that a diver can remain underwater will depend on the depth at which he is working, the amount of air which he can carry, and the rate at which he personally uses it.

b. Examining a shoal or wreck

It is assumed that the shoal or wreck has already been found by normal methods, and that its position is defined by transits or marked by a pellet. The procedure for examining it by diver is as follows:

(i) The parent boat or craft, in which the diving gear is carried, anchors clear of, but close to the object to be examined.

(ii) A dinghy or inflatable craft proceeds to a point directly over the object, towing the diver. One of the men in the dinghy has an ordinary lead line.

(iii) The diver, who is swimming on a float line, holds the lead in his hand, and swims down to the shoal or wreck. When he finds the highest point of the object, or whatever else he is looking for, he makes a pre-arranged signal for the man in the dinghy to take a measurement.

(iv) The dinghy is manoeuvred so that the lead line is up and down, and the lead is tapped on the bottom. The diver watches the lead and makes sure that the measurement is made at the shoalest point.

(v) If there is any difficulty over (iv) the diver may be able to secure the lead line to the object on the bottom. It may then be hauled taut and read top and bottom.

(vi) The procedure is repeated until the diver is satisfied that he has obtained all the information that is needed.

Note that no attempt is made to fix the object on the bottom, whilst the diver is below. If a fix is required, and has not already been obtained, it should be taken after the diving operations are complete.

Although no hard and fast rules can be laid down, it will nearly always be best to undertake surveying diving operations as a special task. In the most favourable circumstances a surveyor who is boat sounding and discovers a shoal may be able to dive on it there and then; but usually the man who interrupts his boat sounding or sweeping activities to go diving will be in danger of wasting more time than he saves.

c. The identification of wrecks (P.A.)

It sometimes happens that a surveyor is not able to say with absolute certainty that an object which he has found with sonar equipment and swept in the usual way must be a wreck (P.A.) whose charted (and probably only too approximate) position lies perhaps two or three miles away. In such cases a diver can provide conclusive evidence, and save a great deal of time.

The two examples below show the sort of thing that can be done.

EXAMPLE I

The wreck of a 'light craft' which had sunk three years previously had to be searched for, fixed and swept. No details concerning it could be obtained, except the fact that its quoted position was not very reliable.

Sonar sweeping quickly found an object lying half a mile away from the charted position of the wreck, in five fathoms of water. There seemed to be nothing else within a radius of one mile.

A free swimming diver, who was also a trained surveyor, was sent to investigate it, using the procedure described in **b** above. After an initial dive of five minutes he returned to the surface and announced that the 'light craft' was in fact a light-float, whose name was still quite legible. In half an hour he measured the least depth over this craft, and made certain that there was nothing dangerous within 50 feet of it.

The whole operation of finding and dealing with this wreck took one day. Had the diver not been available it would have taken at least two, and perhaps three days to obtain a far less complete picture.

EXAMPLE 2

A dangerous wreck (P.A.) was charted right on the most desirable approach route to a busy river estuary, in about 11 fathoms of water. Its presence made it necessary to mark a diverted route with an otherwise unnecessary light-float. This wreck had to be searched for, fixed and swept. Enquiries revealed that it had been a 'landing ship tank', converted for commercial use.

A sonar sweep eventually found two not very good 'echoes' nearly six miles from the charted position of the wreck. One of these 'echoes' was clearly known to the local fishermen, as it was surrounded by fishing floats.

After some preliminary investigations by echo sounder, a free swimming diver was sent down. He came up after a few minutes, to say that two three-ton lorries and a pile of very large rubber tyres were lying on the bottom. The wreck itself lay a short distance away, and was soon found. It was upside down, and the highest point on it was its rudder blade; the diver was able to read its name and port of registration.

This investigation took three days, most of it spent in sonar sweeping. Without the evidence of the diver the surveyor in charge would have been unable to say that he had found the wreck he was looking for. With it there was no doubt at all, despite the poor sonar response.

d. Use of a towed diver

If the water is very clear it may be attractive to tow one or more divers behind a boat. Under good conditions two men, placed fairly close together and each watching his own side, might well clear a path 50 yards wide.

Unless a diver has some form of shielding from the flow of water past him, it will not be possible to tow him at more than two knots and still expect him to do any useful work. Several types of underwater sledge are available on the commercial market. The best of these not only protect the diver from the flow of water, but enable him to plane up and down, bank and divert slightly from the line of advance like the pilot of a towed glider.

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809. Dmd. 632774. K40. 12/69. S.P. & S. **(G.P. 3319)**

TABLE FOR CONVERTING METRES TO FEET AND FATHOMS

Metres	Feet	Fms.	Metres	Feet	Fms.
1	3·281	0·547	51	167·323	27·887
2	6·562	1·094	52	170·604	28·434
3	9·843	1·640	53	173·885	28·981
4	13·123	2·187	54	177·165	29·528
5	16·404	2·734	55	180·446	30·074
6	19·685	3·281	56	183·727	30·621
7	22·966	3·828	57	187·008	31·168
8	26·247	4·374	58	190·289	31·715
9	29·528	4·921	59	193·570	32·262
10	32·808	5·468	60	196·850	32·808
11	36·089	6·015	61	200·131	33·355
12	39·370	6·562	62	203·412	33·902
13	42·651	7·108	63	206·693	34·449
14	45·932	7·655	64	209·974	34·996
15	49·213	8·202	65	213·255	35·542
16	52·493	8·749	66	216·535	36·089
17	55·774	9·296	67	219·816	36·636
18	59·055	9·843	68	223·097	37·183
19	62·336	10·389	69	226·378	37·730
20	65·617	10·936	70	229·659	38·276
21	68·898	11·483	71	232·940	38·823
22	72·178	12·030	72	236·220	39·370
23	75·459	12·577	73	239·501	39·917
24	78·740	13·123	74	242·782	40·464
25	82·021	13·670	75	246·063	41·010
26	85·302	14·217	76	249·344	41·557
27	88·583	14·764	77	252·625	42·104
28	91·864	15·311	78	255·906	42·651
29	95·144	15·857	79	259·186	43·198
30	98·425	16·404	80	262·467	43·745
31	101·706	16·951	81	265·748	44·291
32	104·987	17·498	82	269·029	44·838
33	108·268	18·045	83	272·310	45·385
34	111·549	18·591	84	275·591	45·932
35	114·829	19·138	85	278·871	46·479
36	118·110	19·685	86	282·152	47·025
37	121·391	20·232	87	285·433	47·572
38	124·672	20·779	88	288·714	48·119
39	127·953	21·325	89	291·995	48·666
40	131·234	21·872	90	295·276	49·213
41	134·514	22·419	91	298·556	49·759
42	137·795	22·966	92	301·837	50·306
43	141·076	23·513	93	305·118	50·853
44	144·357	24·059	94	308·399	51·400
45	147·638	24·606	95	311·680	51·947
46	150·919	25·153	96	314·961	52·493
47	154·199	25·700	97	318·241	53·040
48	157·480	26·247	98	321·522	53·587
49	160·761	26·794	99	324·803	54·134
50	164·042	27·340	100	328·084	54·681

Metres	Feet	Fms.
200	656·17	109·36
300	984·25	164·04
400	1312·34	218·72
500	1640·42	273·40
600	1968·50	328·08
700	2296·59	382·76
800	2624·67	437·45
900	2952·76	492·13
1000	3280·84	546·81
2000	6561·68	1093·61
3000	9842·52	1640·42
4000	13123·36	2187·23
5000	16404·20	2734·03
6000	19685·04	3280·84
7000	22965·88	3827·65
8000	26246·72	4374·45
9000	29527·56	4921·26
10000	32808·40	5468·07

Metres	Inches
0·10	3·937
0·20	7·874
0·30	11·811
0·40	15·748
0·50	19·685
0·60	23·622
0·70	27·559
0·80	31·496
0·90	35·433
1·00	39·370

Factors: 1 metre= 3·280839895 feet or 39·370078740 inches
= 0·546806649 fathoms

N.P.134 b (5)

ADMIRALTY MANUAL OF HYDROGRAPHIC SURVEYING

VOLUME TWO

CHAPTER 5

Coastlining and Topography

1973

Published by

THE HYDROGRAPHER OF THE NAVY
TAUNTON, SOMERSET

TABLE FOR CONVERTING FEET AND FATHOMS TO METRES

Feet	Fms.	Metres
1		0·305
1·5	¼	0·457
2		0·610
3	½	0·914
4		1·219
4·5	¾	1·372
5		1·524
6	1	1·829
7		2·134
8		2·438
9	1½	2·743
10		3·048
11		3·353
12	2	3·658
13		3·962
14		4·267
15	2½	4·572
16		4·877
17		5·182
18	3	5·486
19		5·791
20		6·096
21	3½	6·401
22		6·706
23		7·010
24	4	7·315
25		7·620
26		7·925
27	4½	8·230
28		8·534
29		8·839
30	5	9·144
31		9·449
32		9·754
33	5½	10·058
34		10·363
35		10·668
36	6	10·973
37		11·278
38		11·582
39	6½	11·887
40		12·192
41		12·497
42	7	12·802
43		13·106
44		13·411
45	7½	13·716
46		14·021
47		14·326
48	8	14·630
49		14·935
50		15·240

Feet	Fms.	Metres
51	8½	15·545
52		15·850
53		16·154
54	9	16·549
55		16·764
56		17·069
57	9½	17·374
58		17·678
59		17·983
60	10	18·288
61		18·593
62		18·898
63	10½	19·202
64		19·507
65		19·812
66	11	20·117
67		20·422
68		20·726
69	11½	21·031
70		21·336
71		21·641
72	12	21·946
73		22·250
74		22·555
75	12½	22·860
76		23·165
77		23·470
78	13	23·774
79		24·079
80		24·384
81	13½	24·689
82		24·994
83		25·298
84	14	25·603
85		25·908
86		26·213
87	14½	26·518
88		26·822
89		27·127
90	15	27·432
91		27·737
92		28·042
93	15½	28·346
94		28·651
95		28·956
96	16	29·261
97		29·566
98		29·870
99	16½	30·175
100		30·480

Feet	Fms.	Metres
102	17	31·090
108	18	32·918
114	19	34·747
120	20	36·576
126	21	38·405
132	22	40·234
138	23	42·062
144	24	43·891
150	25	45·720
156	26	47·549
162	27	49·378
168	28	51·206
174	29	53·035
180	30	54.864
186	31	56·693
192	32	58·522
198	33	60·350
204	34	62·179
210	35	64·008
216	36	65·837
222	37	67·666
228	38	69·494
234	39	71·323
240	40	73·152
246	41	74·981
252	42	76·810
258	43	78·638
264	44	80·467
270	45	82·296
276	46	84·125
282	47	85·954
288	48	87·782
294	49	89·611
300	50	91·440
306	51	93·269
312	52	95·098
318	53	96·926
324	54	98·755
330	55	100·584
336	56	102·413
342	57	104·242
348	58	106·070
354	59	107·899
360	60	109·728
366	61	111·557
372	62	113·386
378	63	115·214
384	64	117·043
390	65	118·872
396	66	120·701
402	67	122·530
408	68	124·358
414	69	126·187
420	70	128·016

Feet	Fms.	Metres
426	71	129·845
432	72	131·674
438	73	133·502
444	74	135·331
450	75	137·160
456	76	138·989
462	77	140·818
468	78	142·646
474	79	144·475
480	80	146·304
486	81	148·133
492	82	149·962
498	83	151·790
504	84	153·619
510	85	155·448
516	86	157·277
522	87	159·106
528	88	160·934
534	89	162·763
540	90	164·592
546	91	166·421
552	92	168·250
558	93	170·078
564	94	171·907
570	95	173·736
576	96	175·565
582	97	177·394
588	98	179·222
594	99	181·051
600	100	182·880

Feet	Metres
700	213·360
800	243·840
900	274·320
1000	304·800

Fms.	Metres
200	365·760
300	548·640
400	731·520
500	914·400
600	1097·280
700	1280·160
800	1463·040
900	1645·920
1000	1828·800

Inches	Ft.	Metres
1	0·083	0·025
2	0·167	0·051
3	0·250	0·076
4	0·333	0·102
5	0·417	0·127
6	0·500	0·152
7	0·583	0·178
8	0·667	0·203
9	0·750	0·229
10	0·833	0·254
11	0·917	0·279
12	1·000	0·305

Factors

1 Inch = 0·0254 metres
1 Foot = 0·3048 metres
1 Fathom = 1·8288 metres
or 6 feet

N.P.134 b (5)

ADMIRALTY MANUAL OF HYDROGRAPHIC SURVEYING
VOLUME TWO

CHAPTER 5

Coastlining and Topography

1973

Published by
THE HYDROGRAPHER OF THE NAVY

To be obtained from
Agents for the Sale of Admiralty Charts

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This Chapter supersedes the whole of Chapters XII and XIII of the Admiralty Manual of Hydrographic Surveying (1948 Edition)

Price £1.35

Reproduced in England for Her Majesty's Stationery Office by Hobbs the Printers of Southampton
(2230) Dd0569395 1,500 12/78 G3927

FOREWORD

Part 1 of this Chapter deals with coastlining and the use of air photographs as an aid to the coastliner but not with photogrammetry which will be covered in a separate chapter.

Part 2 describes the fixing and delineation of shore topography in as much detail as is likely to be required by the hydrographic surveyor.

Reference is made to Volume I of this work to which it is assumed that the reader will have access. Metric units have been used when they are appropriate.

The text has been written by Lt. Cdr. D. R. Benson, R.N., assisted by Lt. Cdr. T. McAndrew, R.N., and edited by Commander J. S. N. Pryor, R.N.

G. P. D. HALL,
Rear-Admiral
Hydrographer of the Navy

CHAPTER 5

Coastlining and Topography

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CHAPTER 5 *Coastlining and Topography*

Part 1 - Coastlining

1. Introduction

The accurate delineation of the coastline and coastal features is an essential feature of a hydrographic survey since the mariner is often required to fix his position by bearings and angles or ranges to promontories and similar features of the coastline; it is therefore important that every detail which can be represented on the scale of the survey be carefully fixed and charted. The nature of the foreshore must be clearly distinguished by the use of appropriate symbols since this will assist the mariner in recognising the coast and in selecting landing places, etc.

In hydrographic surveying, the coastline is defined as the 'high water line'; on a cliffy coast, where the tide reaches the foot of the cliffs, or on a steep beach, the demarcation of the high-water line is clear; on a gently shelving beach, it is more difficult to judge but generally speaking the line of driftwood, flotsam and jetsam farthest up the beach gives the best idea of the position. In mangroves and salt water marshes where high tides flood the land, the seaward limit of the vegetation is taken as the coastline and is shown by a pecked line with the appropriate land symbol on the landward side.

In land surveying, the coastline is generally defined as the 'line of High Water Ordinary Spring Tides (H.W.O.S.T.)', which is much the same as the high water line. However, in many land surveys, the coastline is delineated solely from air photographs and it is not always easy to identify the high water line with any certainty from air photographs. The coastline also changes its shape and position by accretion, erosion, land reclamation and development. For these reasons the coastline is normally never transferred from existing maps to a hydrographic survey, although the topography may be (see section 10): it is either re-surveyed by 'walking over' it, fixing by the best means available, or checked on the ground against the map, again by walking over it but fixing less frequently.

a. Coastal detail required

Detail which cannot be shown on the fair sheet on the scale of the survey should be included with the coastal description in the Sailing Directions. The coastliner should therefore carry out the following tasks:

(i) Delineate and fix the coastline by the best means available.

(ii) Fix and describe all objects conspicuous to the mariner which are not already fixed, even though they may be a little inland.

(iii) Fix and describe or indicate on the chart all objects and features of the coastline which would assist the mariner to fix himself and identify the coastline. In large scale surveys this will include very minor detail which can only be seen close inshore.

(iv) Measure or estimate the heights of all such features. Some features can be described in general terms such as "Low red cliffs, 5 to 6 metres high".

(v) Fix all islands, visible offshore dangers and obtain their heights.

(vi) Describe the composition of the beach between the low water line (drying line) and high water line as well as above the high water line. The appropriate symbol (sand, rocks, etc.) should be inserted on the fair sheet.

(vii) Indicate established landing places along the coast. Fix and describe groynes, sewer outfalls and anything that might constitute a danger to landing. Piers and jetties should also be fixed and a full description obtained, which should include type of structure, depths alongside, height of deck above M.H.W.S. and facilities available.

(viii) Details of harbours should be obtained giving berthing, facilities and supplies available and included with the Sailing Directions.

(ix) Where appropriate, correct spelling of place names should be obtained from reliable local sources and checked with names shown on existing maps or charts (see section 9).

In addition the coastliner may concern himself with topographical detail near the coast. The amount of detail will depend on the time available, the scale of the survey and whether the topography is going to be obtained by another field party or by other means such as air photography.

The scale of the survey must be constantly kept in mind while coastlining so that time is not wastefully expended in delineating by accurate measurement small features and indentations of the coast which cannot be fully represented on the sheet when the coastline is plotted. For example, on a scale of 1:25,000 a length of 25 metres is represented by 1 mm on the plotting sheet. Therefore paced or estimated distances and compass bearings may be quite adequate for positioning certain minor detail.

b. Marking the Coast

The locations of stations and marks for a hydrographic survey are often mainly arranged from the point of view of their convenience for fixing the soundings. Some consideration, however, should be given to the coastliner and topographer in their work. When visual methods are used, soundings and coastline may be fixed by sextant and station pointer. Although other ways of fixing are available on land the work of the coastliner will be made much easier if he can be provided with suitable marks to check his position at frequent intervals by resection.

Marks situated offshore, on islets and other off-lying features such as fish stakes and groynes, etc., often provide the most convenient method of control for fixing the coastline. In rivers and gulfs, marks on the opposite shore will be useful provided they are not too distant.

On low coastlines it may be possible to site marks some distance inland where they will serve well for coastlining and for fixing soundings close inshore.

Floating marks tautly moored offshore may be used for small scale surveys but their use is not recommended for surveys on scales larger than 1:30,000.

When the shore is fringed with trees or there are no off-lying islets and the scale of the survey is too large to use floating marks, it may be impossible to provide marks suitable for resection on the coastline. In such cases, the best that can be done is to place them in such positions that they see along the coast as far as possible in each direction, adjacent ones being intervisible where possible, and to fix these by "shooting up" from ship or boat.

The density of the control will chiefly depend on the scale of the survey. For example, on a scale of 1/50,000, marks spaced at intervals of a mile or so (i.e., 4 cms on the paper) along the coast should generally suffice. On a scale of 1/12,500 marks at intervals of about a third to half a mile (i.e., 6 cms on the paper) may be required. These figures should only be regarded as a rough guide. Marks at greater intervals may still provide sufficient control on some coasts.

On the other hand, if the configuration of the coastline is very complicated, marks may have to be spaced more closely.

In a hydrographic survey controlled by an electronic fixing system, such as "Hifix", the coast will have to be marked solely from the point of view of coastlining and the inshore sounding by boats.

c. Methods of Coastlining

If possible a boat should accompany the coastlining party. It is useful for carrying gear not actually in use at the time and may be required for crossing rivers, negotiating awkward parts of the coast or for visiting off-lying rocks, banks or islets which require fixing and from which it may be convenient to observe.

The main methods of coastlining are enumerated below and are more fully described in the sections indicated:

(i) By station pointer fixes (Section **2**).

(ii) By traverse (Section **3**).

(iii) By coasting and "shooting up" from the ship or boat (Section **6**).

(iv) By the use of maps and air photographs (but see the cautionary remarks in Section **1(a)** above and in Section **8**).

Usually a stretch of coastline is fixed by more than one of the methods mentioned and very often a combination of methods is used.

2. Coastlining using Station Pointer Fixes

In some circumstances it is possible to get good station pointer fixes at almost any point of the coast. The observer occupies a series of stations on the high water line and at each obtains sufficient angles to the fixed marks of the survey to fix himself and, whenever possible, a check angle to check the fix. The distance apart of these stations will depend on the scale of the survey and the complexity of the coastline. The horizontal angles are normally obtained by sextant, but if the coastline is being delineated by theodolite or level traverses, those instruments will naturally be used.

In addition to fixing himself, the coastliner should also take angles to offshore dangers, tangents of islands and along the trend or "general direction" (GD for short in field records) of the coastline onwards towards the next station and backwards towards the previously occupied one. The "general direction" must, of course, be along the high water line from the station being occupied and not necessarily to the previously occupied station. If the stations are sufficiently close together "on the paper", the coastline can be drawn in with all the required precision by plotting all the stations and the "general directions" from them.

This method is chiefly applicable to work on small scales and where the coastline is not too intricate. When the configuration is irregular, it is usually more convenient to combine it with a traverse method.

3. Coastlining by Traverse

A much used method of fixing the coastline is by means of traverse between adjacent surveying marks. Volume 1 Chapter 8 of this manual describes in detail the principles of traversing and the corrections to be applied. In coastlining work the traverse can be plotted graphically and corrections, if any, also applied graphically. The method of traversing used will depend on the precision required which will depend on the scale of the survey.

Whatever method is used, the general principle is the same. The observer starts the traverse from some known position which may not actually be on the high water line, i.e. a sounding mark or station pointer fix. He then fixes a series of points in the vicinity of the high water line, by distance and angle or bearing between them, to enable the coastline to be drawn in with the required accuracy. The traverse must "close" on another known position to establish the accuracy of the work.

The lengths of the legs of a traverse will depend on the scale of the survey, the intricacies of of the coast and the method used to obtain distance. When distance is measured by tachymetry or sextant and 10 foot pole (see Volume 1, Chapter 3), the lengths of the legs should be limited to 200 metres (650 feet) being as much as can be measured with sufficient accuracy by those methods. In difficult conditions a 20 foot pole can be used to enable longer distances to be measured. Observations for angle or bearing are made at each end of the traverse and at each "turning point" to as many "intermediate points" as may be necessary for plotting the high water line. The distance apart of the intermediate points must also depend on the scale of the survey and on the configuration of the coast. If the configuration is involved, it may be necessary to fix a series of intermediate points not more than 5 mm apart on the paper so that the coastline can be accurately drawn in. On a scale of 1/5,000 this would correspond to about 25 metres, whilst on a scale of 1/50,000 it would be about 250 metres.

The positions of the turning points are plotted direct on the field board by protracting the angle or bearing and length of each leg in succession, starting from the initial station (this is more fully described in Section **5**). The accuracy of the work is established by the close of the plot on the final station. If the amount of misclosure is acceptable, the traverse can be adjusted as described below in Section **3c**. This practice can be accepted on the understanding that the coastliner will never be required to run traverses of any great length without independent checks on his position at frequent intervals by station pointer fix or by closing on a fixed mark. A sufficient number of fixed coastal marks should be provided to keep the total length of any coastline traverse between marks or fixes within a limit of 10 cms, as measured on paper. In this way, each traverse can be individually adjusted and no appreciable errors will accumulate in the plotting.

Methods of traversing suitable for coastlining under various conditions can be enumerated as follows:

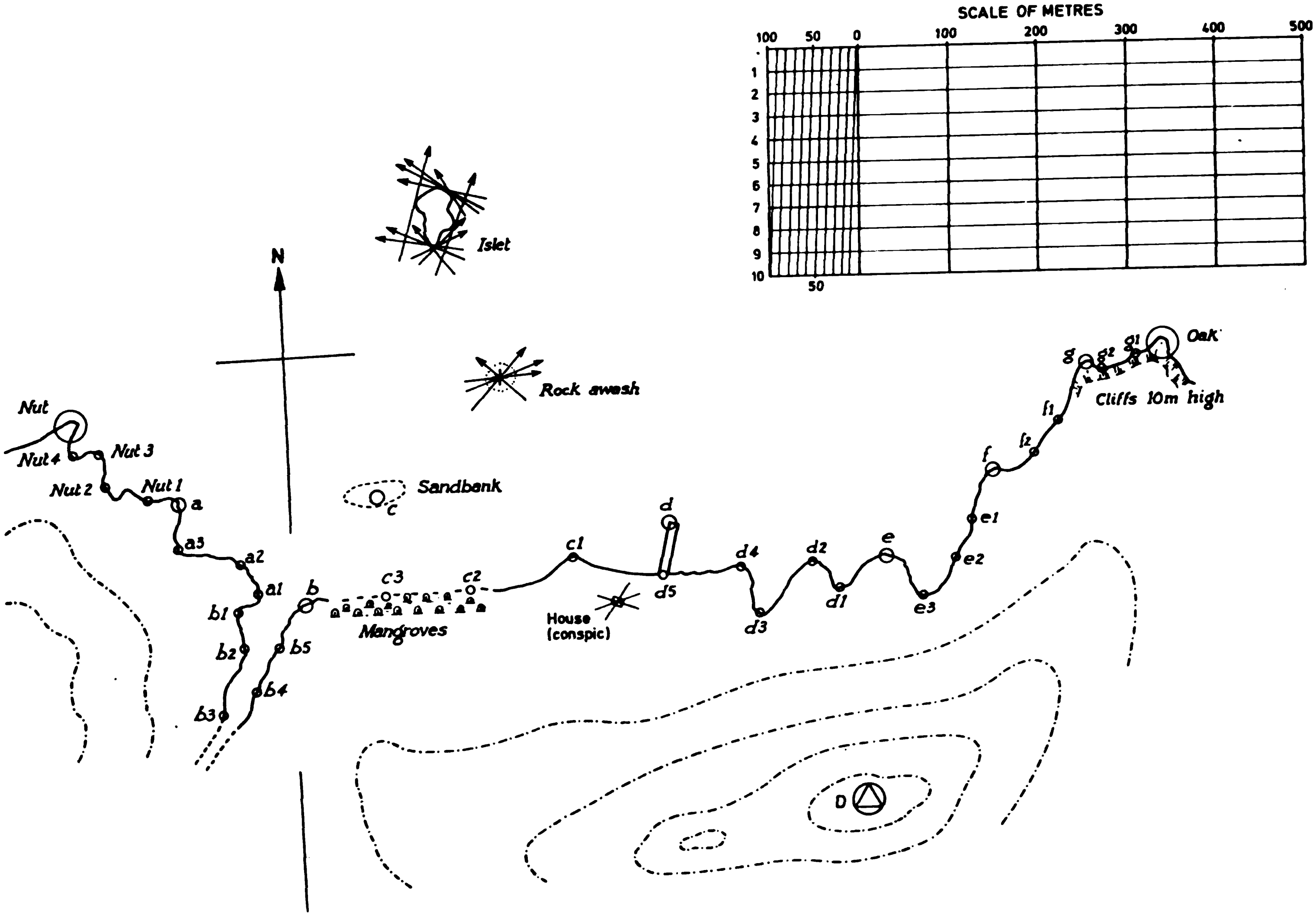
(i) By theodolite traverse using tachymetry. For the most purposes a level, fitted with a horizontal circle, would do as well and is more convenient. This methods should be used for coastlining on all scales of 1/12,500 or larger.

(ii) By sextant and 10 foot pole (See Volume 1, Chapter 3). This is the most common method used and is suitable for scales of 1/25,000 and smaller.

(iii) By compass traverse using a marked line 100 metres long or portable rangefinder. This method is usually only suitable for scales smaller than about 1/50,000.

(iv) By beach traverse (see Volume 1, Chapter 8). This method is very suitable for any work over a long expanse of beach using the minimum of equipment. This consists of a 50 metre tape and a length of wire, generally about 100 metres) marked every 20 metres. The method is also described in sub-section **3b** below.

In most of the work it is only necessary to protract short rays on the paper to plot the traverse and the intermediate points. Such rays only need to be observed to an accuracy of, say, 10′ of arc. On small scales (and even on large scales for short rays), the nearest degree, as obtained by prismatic compass, will often give the required direction with the necessary precision. For example, on a scale of 1/50,000 an error of 1° in bearing on a ray a mile long (3·7 cms on the paper) would transpose the terminal point only 0·6 mm when plotted on the paper. Errors in plotting can be considerably greater unless care is taken.



PORTION OF COASTLINE FIELD BOARD

FIG 5-1

a. Description of a typical coastline traverse

In a survey on a scale of 1:12,500 it is required to fix the coastline between two sounding marks, 'Nut' and 'Oak' as shown in Fig. 5–1. As the scale is large, this should be done with a theodolite (a level fitted with a horizontal circle may be used if elevations and depression angles are not required) and a levelling staff for obtaining angles and distances by tachymetry. A small rangefinder may also be useful; several ranging poles, a 25 metre linen tape, pocket prismatic compass, watch and field book will also be required. It will generally be found wiser not to attempt to plot the coastline in the field since the board will inevitably become soiled, or get wet, and time will not be spent doing work which can probably be better done in the greater comfort of the ship or drawing office. Coastline should not be plotted on the same boards as soundings. Each coastline board should have a diagonal scale on it as shown in Fig. 5–1 and should show the positions of main and secondary stations and sounding marks. The surveyor should also carry, in a polythene or other transparent, waterproof cover, a copy of the latest chart or map of the area to be surveyed or, if none is available, a sketch or diagram, upon which all the main and secondary stations and sounding marks have been plotted; also a copy of the latest air photographs if available.

The coastliner must be accompanied by a staff man; an assistant to keep the coastline record in the field book and a man to tend the boat or dinghy if possible. The surveyor in charge of the party may often find it convenient to keep the record himself while his assistant takes the observations.

The party lands at "Nut" and the instrument is set up over the mark. Using "Oak" or "D" as a reference object, the observer looks along the coast and obtains angles to any prominent objects that are visible, such as tangents to islands and headlands, summits or hills, etc. Elevations should be taken to hills and a depression to a shore horizon (with a time) for height determination (see Volume 1, Chapter 9). In this instance, the coastliner sees an islet and obtains tangents and an elevation to it and a depression to a shore horizon. He also sees a rock awash, the end of a pier *d*, and observes rays to them.

Meanwhile the staff man has been directed to proceed to the next turning point of the traverse, *a*, where he sets up the staff vertically on a "crow's foot" placed on the high water line and the horizontal angle to it from the zero, and the three tachymetric readings, are observed and recorded. At a signal from the surveyor, the staff man, leaving the crow's foot in place, starts to return towards the surveyor walking along the high water line and stopping at every point where the coastline makes a change of direction appreciable on the scale of the survey. At each of these intermediate points, called "Nut 1", "Nut 2", etc., angles and tachymetric readings are observed to the staff. After the last observations, in this case at "Nut 4", the party proceed together to *a*, where the surveyor points out to the staff man the next turning point *b*. The level is set up over the position of the crow's foot, the staff man proceeds to *b*, the observer zeros on "Nut" and takes shots to "P" and "Q" and the staff at *b*; the staff man returns, stopping for observations at *a1*, *a2* and *a3*.

Turning point *a* is then marked with a ranging pole (leaving the assistant temporarily behind if one is with the party). The staff man had had to cross a small river, out of sight from *a*, to get to *b*, so the surveyor now carries on to *b* and sets up the instrument, then takes shots into the staff as the staff man rejoins him, stopping at intermediate points *b1*, *b2*, etc., round the banks of the river. (Had the river been of considerable size or importance, *a1* could well have been made the second turning point and the traverse continued round the banks.) At *b* the coastliner has noticed that the coastline beyond *b* consists of mangroves and would be difficult to walk over. However, he notices an off-lying uncovered sandbank and when the staff man returns sends him to it by boat (with the crow's foot, which had been left at *b*) and observes the angle from the ranging pole at *a* to the staff at *c* on the sandbank and takes the tachymetric readings, thus making *c* the next turning point in his traverse. He notes the "G.D. On" along the mangroves, recovers the ranging pole from *a*, leaves it at *b* and the party foregather at *c*. There the next turning point *d* is selected on the pierhead, the staff man despatched thither to return via *c1* and *c2* at the far end of the mangroves. An angle at *c* and a rangefinder distance will suffice to fix the position of the mangroves at *c3* (and save the staff man having to plod through the mud). The ranging pole is stuck in at *c* and the party proceed to *d*; in a similar way the traverse is carried through *e*, *f* and *g* to close on "Oak", where the angle from *g* to an independent zero should also be observed.

The following principles which underly the foregoing description should be noted:

(i) The coastliner should make sure of his main traverse first before taking observations to intermediate points. Although this entails some loss of time due to the staff man walking back and forth, it reduces the chance of an incomplete traverse, which is a common source of error, and also gives the coastliner real control over the staff man. In some cases, as between *a* and *c*, the terrain requires a departure from this principle, but it should generally be followed. The use of small radio telephones may well enable different procedures to be adopted to suit the terrain being surveyed and save much time in keeping control of the staff man and assistants.

(ii) Although sounding marks or main stations can be used as the reference object for observations of horizontal angles in the traverse, the accuracy is enhanced if the angle between the turning points on either side of the observer (known as the back and front marks) is measured. However, horizontal angles to distant objects such as the islet or the rock awash should be zeroed on a sounding mark or main station at least as far distant as the object being observed to. In this example "Nut", "Oak" or the main station on the hill at "D" should be used as the zero or reference object.

(iii) Observations should be made to all tangents and prominent objects from each turning point; it may not be necessary to plot all the rays.

(iv) If a good resection fix is available at any turning point in a traverse it should be taken, with angles to the nearest minute of arc, as a check on the accuracy of the traverse. Similarly, check angles to any points which have been, or will be, occupied should always be obtained so that the accuracy of the work can be tested.

(v) When traversing with a sextant, the angle between back and front marks, which often exceeds 140°, will have to be measured in two parts using a common intermediate point; both parts of the angle should be written down and no attempt made to add them in one's head if errors are to be avoided.

Notes should be made in the field book as the work progresses concerning the nature of the foreshore and of the country immediately inland. The heights of cliffs, sand dunes, etc., along the foreshore should be measured or estimated and notes made on the extent and height of drying ledges and banks, together with the time: dimensions of piers, including height above the water (with time) should be noted.

b. Coastlining by Beach Traverse

A Beach Traverse is described in Volume I, Chapter 8. This method may be used for coastlining where the foreshore is conveniently flat and the coastline not too complex. For convenience, the measuring wire used is normally about 100 metres long, marked distinctively with bunting every 20 metres. Two assistants handle the wire and work ahead of the surveyor. When the length of a leg of the traverse exceeds the length of wire, the line of the leg for each fleet of the wire is maintained by the front assistant driving a ranging pole into the ground on the transit of the back assistant's ranging pole and the last turning point, marked by a ranging pole.

The direction of each leg is measured by sextant or compass or for precise work, by measuring "offsets". Distances at right angles to each leg of the traverse are measured to the high water line and to other detail from known distances along the wire. For small scale

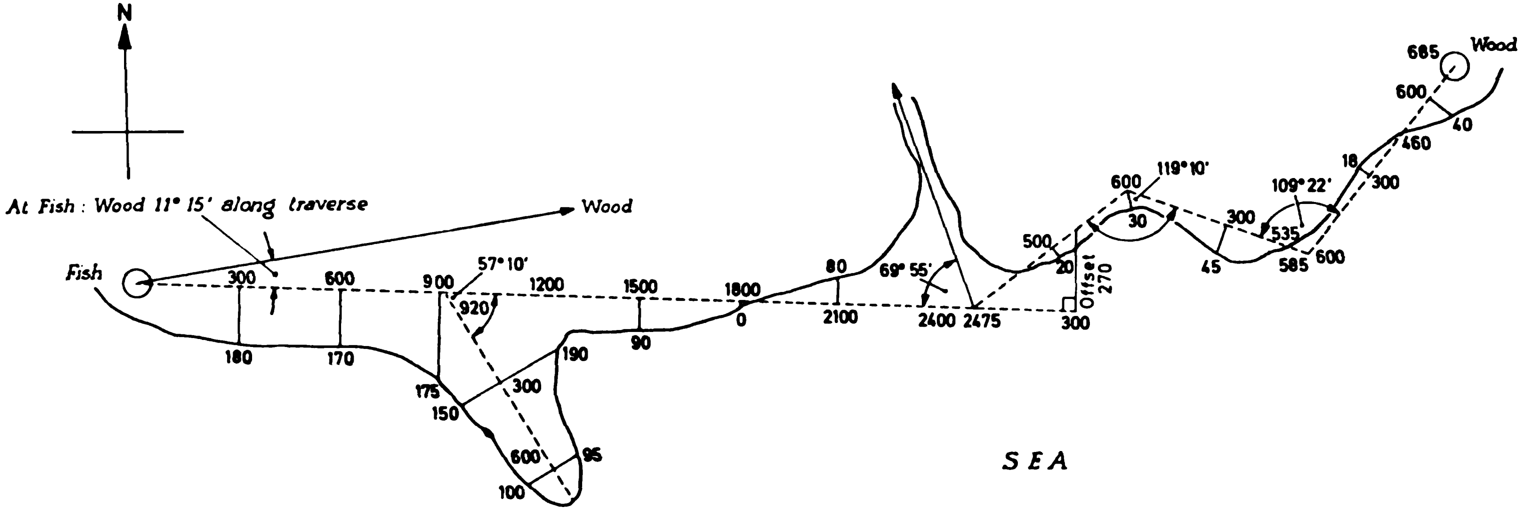

N
At Fish : Wood 11° 15' along traverse
Wood
Fish
57° 10'
1500
1800
69° 55'
2400 2475
Offset
119° 10'
109° 22'
Wood
SEA

FIG 5-2

work such measurements can be done by pacing. In this way coastline and other detail can be plotted and drawn. Occasionally short "hanging" traverses may have to be used to delineate promontories and features of secondary importance.

Records for this type of traverse can be conveniently kept on a rough sketch in a field book as shown in Fig. 5–2.

c. Adjustment of a Coastline Traverse

The adjustment of a minor traverse by graphical means is fully described in Volume 1, Chapter 8, Section 5(e).

Briefly, the principle is as follows:

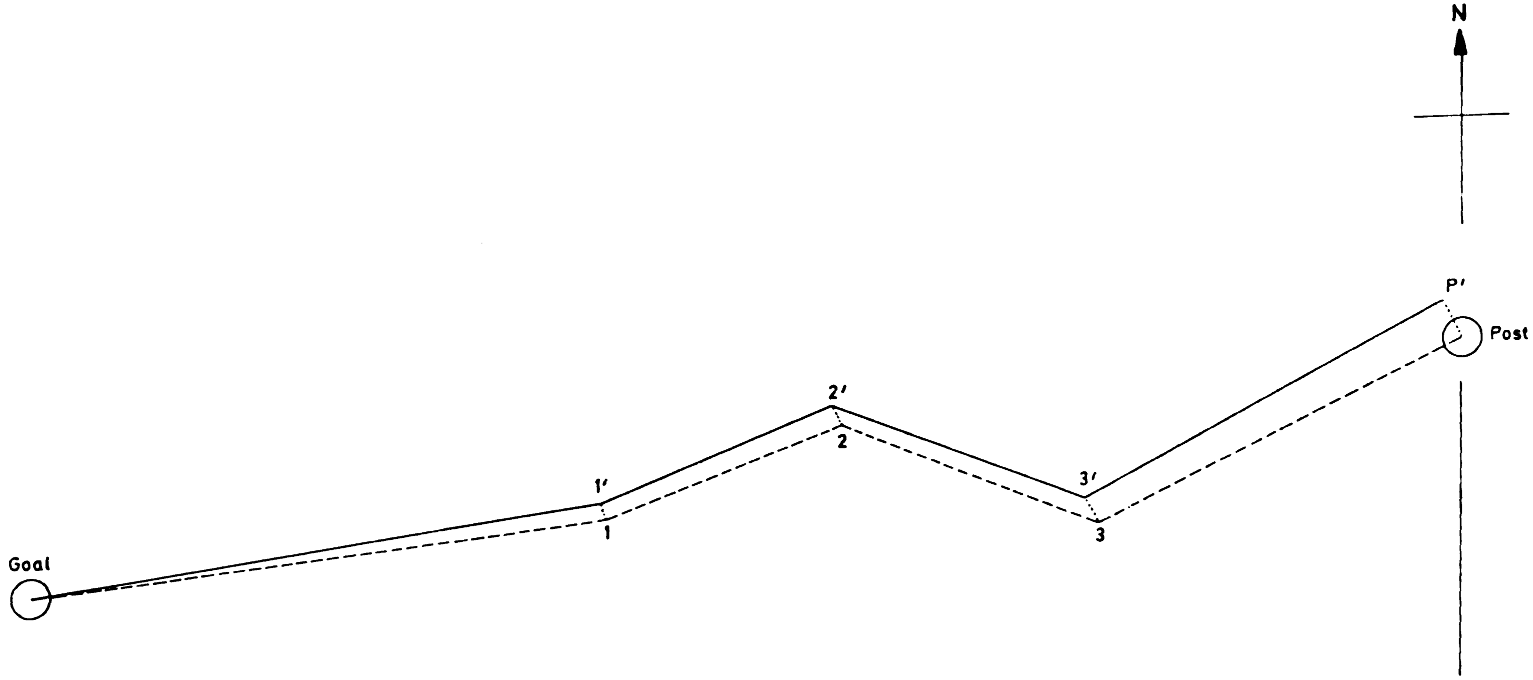
> Fig. 5–3 shows a traverse between the two points "Goal" and "Post". The firm line shows the traverse as first plotted, which terminates at P′ instead of "Post". A line is drawn from P′ to "Post" and short lines, parallel to this, are drawn through each turning point, 1′, 2′ and 3′. The lengths of these short lines are made proportional to their distance from the starting point "Goal" in relation to the total distance P′ – Post, along the traverse. The line, shown pecked in Fig. 5–3, joining the extremities of these short lines is then the adjusted traverse.

4. Coastlining records

It is not necessary to lay down a stereotyped method for recording observations taken in coastlining. The basic rules to be followed are that all the observations made must be recorded; that the actual observations are entered (i.e., tachymetric observations are recorded as the 3 staff readings, or as the angle observed to a 10 ft. pole, and not as the deduced distance; if a sextant angle is observed in two parts, each is recorded separately, not the whole angle obtained by mental addition). A freehand sketch drawn at the time as the work progresses should accompany the observations and will be an invaluable aid when plotting the coastline at the end of the day's field work.

It will probably be found most convenient to use a double page of the field book, one for the sketch and the other for the related observations. It may also be useful to carry an extract from the 10 foot Pole Table, or a metres-to-feet conversion table if using a metric tach-staff, in the cover of the field book as this helps to keep the scale consistent when sketching.

See example on page 11 of a page of the field book used in the traverse described in Section **3a.**



GRAPHICAL ADJUSTMENT OF A TRAVERSE

FIG 5-3

Example of record in coastline field book

Survey: Cape Nuthouse to Oaken Point
Scale: 1/12,500
Date: 23 August 1973

at NUT Time 1030 10m inshore from HWL

D ⌖ 360° 00′

$$\text{Islet}\left\{\begin{array}{lll}\text{LHE} & 285 & 44\\ & & \\ \text{RHE} & 307 & 21\end{array}\right\}\text{ Dip to shore horizon of islet } 0°35'$$

Rock (awash 327 56
Pier 343 50 seaward end

$$\text{'a'}\quad 010\quad 35\left\{\begin{array}{c}3.615\\2.854\\2.091\end{array}\right\}152.4\text{ m}$$

HWL rock as far as 'a'. Rocky ledges extend seaward for 25 m between 'Nut 1' and 'Nut 3'. Drying sand below ledges. Small bushes above HWL.

$$\text{Nut 1}\quad 017\quad 45\left\{\begin{array}{c}2.61\\2.03\\1.45\end{array}\right\}116.0\text{ m}$$

$$\text{Nut 2}\quad 031\quad 15\left\{\begin{array}{c}2.15\\1.77\\1.39\end{array}\right\}76.0\text{ m}$$

$$\text{Nut 3}\quad 009\quad 24\left\{\begin{array}{c}2.36\\2.13\\1.90\end{array}\right\}46.0\text{ m}$$

$$\text{Nut 4}\quad 052\quad 11\left\{\begin{array}{c}3.72\\3.46\\3.29\end{array}\right\}33.0\text{ m}$$

---

at 'a' Time 1100 On HW line

D ⌖ 360° 00′

$$\text{Islet}\left\{\begin{array}{lll}\text{LHE} & 284 & 12\\ \text{Summit} & 286 & 03\\ \text{RHE} & 289 & 32\end{array}\right\}\text{Elevation to summit } 1°15'$$

Rock awash 313 14

$$\text{'b'}\quad 016\quad 55\left\{\begin{array}{c}3.64\\2.74\\1.84\end{array}\right\}180\text{ m}$$

$$\text{a1}\quad 026\quad 02\left\{\begin{array}{c}2.84\\2.20\\1.56\end{array}\right\}128\text{ m}$$

a2 020 $00\left\{\begin{matrix}2.76\\ 2.28\\ 1.80\end{matrix}\right\}$ 96 m

a3 071 50 49.4 m (tape)

Nut 191 10

---

at 'b' Time 1145 On HWL at entrance to Brown River. Mangroves to E. Grass and nippa palm to S.

Nut ⊕ 360° 00′

'a' 003 40

'c' on sandbank 083 $55\left\{\begin{matrix}2.60\\ 1.90\\ 1.20\end{matrix}\right\}$ 140 m

Islet $\left\{\begin{matrix}\text{LHE} & 066 & 12\\ \text{RHE} & 071 & 26\end{matrix}\right.$

b1 .... etc.

b2

b3

b4 .... etc.

b5 265 00 52 m (pacing)

At 1120 Depth in river between a1 and 'b' = 0.6 m.

5. Plotting the coastline

The method of plotting a minor traverse is described in Volume 1, Chapter 8. In the example described above in Section **3a** and Fig. 5–1, the coastline would be plotted as follows:

(i) Prepare a field board by pricking through the positions of all main and secondary stations and sounding marks within the area of the board. Stations which lie on or near the coastline should not be circled in ink at this stage but in pencil: when the coastline has been plotted and inked-in, circles or segments of circles may then be drawn round them in ink. Construct a diagonal scale on the board.

(ii) Plot the turning points by protraction of angle and distance starting from "Nut". It will be found most convenient to use a large circular protractor of transparent plastic, springbow dividers, pricker and well sharpened 4H pencils. It is important to remember to avoid the use of short zeros on the paper for aligning the protractor. When plotting rays, ensure that they are drawn longer than required and that prick-holes made at the edge of the protractor are marked so that they can be used again for aligning the protractor if required. It is important to do this when the reference object is the back mark of the traverse and therefore the zero for plotting would be very short if the back mark prick-hole were used for aligning the protractor or station pointer.

(iii) If there is an acceptable misclosure the traverse should be adjusted graphically as described in Section **3 (c)**. If there is a large misclosure it will often be found to be due to a single gross error rather than an accumulation of minor ones: the plotting should be checked carefully before abandoning hope and re-surveying the section in the field.

(iv) The intermediate points, tangents and plotting shots are then drawn in from the corrected positions of the turning points; care must be taken to zero on the corrected positions of back marks, drawing lines through them upon which to align the protractor.

(v) The detail of the coastline between the intermediate points is then inserted using the sketch map; air photographs and existing maps are of great assistance as is the information noted at the ends of lines by boat-sounders.

(vi) The coastline is then inked-in using the appropriate colours and symbols, shown on Charts D 6067 and 5011. When depicting cliffy or steep coasts, the base of the cliffs must be correctly charted but the tops can be drawn far enough inland to permit the penwork to be inserted; similar exaggeration is necessary with certain other symbols but great care must be taken with those representing low water features to ensure that the seaward limit is correctly charted.

6. Coasting and shooting-up the coastline from the ship or boat

Where the shore cannot be approached owing to breakers or the coastline cannot be walked over because of difficult terrain, such as mangrove swamps, the surveyor must be content to fix the coastline from a boat. The results are generally not so satisfactory as those obtained by walking over the coastline, but on small scales, where minor indentations of the coastline are not appreciable in the plot, a reasonably accurate representation can be attained. This method is often the most convenient and suitable one to delineate the coastlines of small islands.

To coastline by this method the boat proceeds roughly parallel to the shore, stopping at numerous points or "stations" along the coast, anchoring if necessary. At each station occupied by the boat, a station pointer fix (with a check angle, if possible) is obtained and angles observed to as many points as can be identified on the high water line from the boat and to all tangents of land. At least three rays should be obtained to every point from different stations to fix the point. The rays should give a good cut. Rangefinder distances can also be obtained to the nearest point of land and near points of detail from each boat station to fix the coastline.

The coastline can be fixed in a similar way from a ship, using radar to obtain distances. It must, however, be remembered that quite considerable indentations in the coastline can be missed by radar owing to the shadow effect of nearby promontories. Also the radar reflecting surface will not necessarily be the high water line unless the coastline is steep-to. Where fixing very close inshore is difficult or impossible for a boat, because of the disposition of marks, delineation of the coastline can be done from the ship, anchored a suitable distance offshore. The ship fixes the coastlining boat by visual angle and radar distance as it proceeds along the coastline. The boat should be fitted with an efficient radar reflector or transponder and be in radio contact with the ship. The boat must not approach the coast so closely that its echo on the radar screen merges with the coastline and it should proceed along the coast, stopping, as described above, to fix coastal detail from boat stations. Each boat station is fixed from the ship, using radio communication to co-ordinate times and movements of the boat.

7. Heights of Coastal Features

For details of methods of determining the heights of topographical detail, Volume 1, Chapter 9, should be consulted. It should be remembered that all heights as shown on Admiralty charts are measured from "Mean High Water Springs" (see Volume II, Chapter 2).

The simplest method of measuring heights is usually by means of vertical sextant angles from a boat anchored and fixed a little distance offshore. The height of the feature should be calculated by the method described in Volume 1, Chapter 9. A rough value of the height can be obtained by the formula:

$$\text{Height in feet} = \frac{\text{Angle in seconds x distance in nautical miles}}{34}$$

or

$$\text{Height in metres} = \frac{\text{Angle in seconds x distance in nautical miles}}{111}$$

The vertical angles should be measured above the high water line, which is the height datum, if it can be identified from the boat; if not, they can be measured from the water level at the moment and subsequently corrected when the tidal observations are received.

8. Use of Air Photography in Coastlining

The methods of using air photography for charting will be fully discussed in the chapter on Photogrammetry and this section is not intended to describe how photography can be used on its own, but simply to indicate how air photographs can be used as an aid to the coastliner who is surveying the coast principally by other means.

An air photograph shows the water's edge at the moment of its exposure. On shelving beaches this may be some distance from the high water line which may not be identifiable, nor do air photographs give much indication of the nature of the foreshore which can only be determined by inspection on the ground. However, if an overlapping series of recent vertical air photographs can be obtained, upon which a good number of positions fixed on the ground are identifiable, then considerable use may be made of them to save time in surveying the coastline without loss of accuracy. Unimportant features which add to the completeness of the chart, but which are of no great concern to the mariner, such as narrow, unnavigable waterways, limits of swamps, clumps of vegetation on reefs, etc. – need not be charted with such meticulous accuracy and may be inserted direct from air photographs.

If the photographs are being flown specially for the survey, it is worth marking fixed points on the ground beforehand: strips of white bunting about 4 m x 1 m arranged radially at the mark and weighted down with stones have been found suitable. If working from existing photographs, the pocket stereoscope is useful for selecting points on the photographs which can be identified on the ground and fixed.

The photographs should be carried in the field in a waterproof covering and should have marked on them the points, no more than 3 cms apart on paper for the scale of the survey, which can be identified on the ground and fixed in relation to the control for the survey.

Where sufficient resected points cannot be achieved, then additional identifiable points must be obtained by intersection from ships stations offshore or by traversing between the identifiable and fixed points.

Care should be taken to see that shots are taken to off-lying islands, drying reefs, banks and rocks, etc., as the photographs can subsequently be used to insert the shape of these features provided their extent has been determined by tangential shots. Off-lying rocks which cover and uncover which might be overlooked at high water by the coastliner working without the aid of air photographs are often revealed on the photographs and provide a readily identifiable point if fixed from a boat.

When plotting coastline surveyed in this way, the identifiable points are first plotted from the fixes taken or by adjusting the traverses in the usual way. The detail is then drawn in from the photograph using proportional dividers and protractor. It must be constantly borne in mind when doing this that the scale over the photograph is not constant, that the scale of the photograph is that calculated from height and focal length only at the principal point (the point marked with a cross in the centre of the photograph) and that the distortion increases towards the edges. The dividers must be adjusted between each pair of adjacent identified points so that the proportion of distance between points on the photographs and points on the plot is maintained when inserting the intermediate detail; the adjustments will be kept to the minimum if one works as close to the principal points on each photograph as possible, going on to the next photograph before the distortion makes itself apparent. Tangents to islands and banks should be plotted from each point at which they were obtained; the outline should be inserted from the photograph only when they have all been plotted, using proportional dividers but, with practice, this can be done equally well freehand. The island in Fig. 5–1 might well have been coastlined in this way.

The temptation to select the best photographs and have them photo-enlarged or -reduced to the scale of the survey in order to be able to trace off the coastline should be resisted, since the enlargement is rarely exactly correct first time and by the time a print at the correct scale for three or four inches of coastline on paper has been obtained much more could have been done by the method described in the previous paragraph.

9. Place Names

The coastliner and topographer should obtain the correct local names of villages, islands, headlands, rivers and other features of importance from authoritative local sources. The services of an interpreter should be obtained if need be for this purpose and to assist with the proper spelling of the names. Great care must be taken to make sure that the person questioned understands which feature is being indicated: many people do not understand maps and some are reluctant to admit not knowing a name. Whenever possible names should be cross-checked independently if there is any doubt.

Whenever possible official maps of the area should be obtained and provided these are of recent date the names on them should be accepted unless there is reliable local information of a contradictory nature.

10. General

Cartographically, the term "topography" implies the fixing and delineation of land features. A chart is a guide over the sea and, in consequence, soundings, which indicate the form of the sea bed, are the most important part of it. Nevertheless, in coastal waters the mariner must chiefly depend on the land to fix himself and visible land features must be represented on a chart in such a fashion that they will be readily recognisable. Land features must also be fixed in the same framework as the soundings so that any fixes obtained from them plot correctly in relation to the charted sea bed features.

The amount of topography needed in a hydrographic survey depends on circumstances. As a general rule the aim should be to show all the land features which are visible from the sea and as much detail between the most distant features and the coast as time allows in order to give completeness to the survey. On large scale charts, it is obvious that distant hill summits will be outside the borders of the sheet and cannot be shown even though conspicuous to the mariner. On small scales it may be necessary to leave a considerable amount of "dead" ground without much detail shown between such summits and the coast. This can be described in a general manner such as "undulating country, densely wooded".

In hydrographic surveys, the factors governing the amount of topographical detail shown are the means and time available. If good land maps or air photographs are available, much topographical detail can be easily taken from them, provided the land features can be plotted accurately in relation to the framework of the survey. If neither of these are available, more laborious methods in the field will be required. Anything very elaborate, involving the detention of the surveying unit for a period after the sounding and coastlining are completed, cannot often be justified. If sufficient staff is available to undertake topographical surveying simultaneously with sounding and coastlining, there will generally be time to produce a satisfactory map of the principal land features before the sounding is completed.

In addition to individual land features, contour lines are also required to indicate the height and shape of the ground with a reasonable degree of accuracy. The precision need not, however, be as great as that found in a good land survey and form lines, which are contour lines of unspecified height, are often sufficient to achieve this purpose.

The representation of land features is effected by the use of recognised symbols as indicated on charts D6067 and 5011. A certain amount of latitude must be allowed to the draughtsman in using these so that essential detail may be clearly shown. This is particularly the case on small scales where isolated houses, roads, bridges, etc., cannot be drawn true to scale without making the symbols very minute. It is therefore permissible to exaggerate their size to some extent in order that they may be easily seen on the chart. Similarly, in the case of towns, it is impossible to show all the individual streets clearly on any scale smaller than about 1/12,500. On smaller scales therefore it is usual to block in areas between main streets or even whole towns, and only to show the more important and conspicuous buildings individually.

11. Topography from Existing Maps

From the hydrographic surveyor's point of view, it is fortunate that where the topography is complicated by the existence of towns, railways and a road system, good large scale maps are usually available. The mapping of much detailed topography in the field is laborious but these details can quickly and easily be transferred to the chart from the existing large scale maps by one of the methods described below.

The hydrographic surveyor should always endeavour to obtain copies of any land maps covering the coast of the survey, especially if their scale is equal to or larger than the scale of the survey. Such maps will usually show much more topographical detail than could normally be fixed during the progress of the hydrographic work and their use will be a great saving of labour. Some discretion, however, must be exercised in their selection particularly if it is necessary to transfer detail from a smaller scale to a larger one. Such a practice is not generally recommended, except for the transfer of unimportant detail to make the fair sheet complete. The detail of maps should be thoroughly checked in the field; it is desirable to fix a few important points appearing on the particular land map during the progress of the hydrographic work. The angles and distances between these points can then be compared on the map with those on the plotting sheet, and a very good idea of the accuracy of the land survey can then be formed. It is also necessary to inspect on the ground, as far as this can be done, the features appearing on the map in order to ensure that all detail is up-to-date.

a. Squaring down

The usual method of transferring topography from a map to a chart is by the process of squaring down. In this method, two points shown on the map and situated near opposite ends of the survey area are fixed in the hydrographic survey. The two points are joined on the map and on the field board, to which the detail is being transferred, by a straight line which is common to both map and survey. This line is used as a "base" for the squaring down (or up) process and the relative scales of the two surveys are found by a comparison of its length on the map and field board. The ratio of the two lengths should, of course, agree (very nearly) with the ratio of the two natural scales of the respective surveys. Precise agreement will seldom be achieved owing to scale factors for the map and the survey and to paper distortion of the map.

The base lines are then divided into any convenient number of equal parts, the same number on each base line, in such a way that on the smaller scale the divisions are not more than about ¼-in. apart. From the divisions, a system of corresponding squares is drawn on either side of the base lines extending sufficiently far to cover the area.

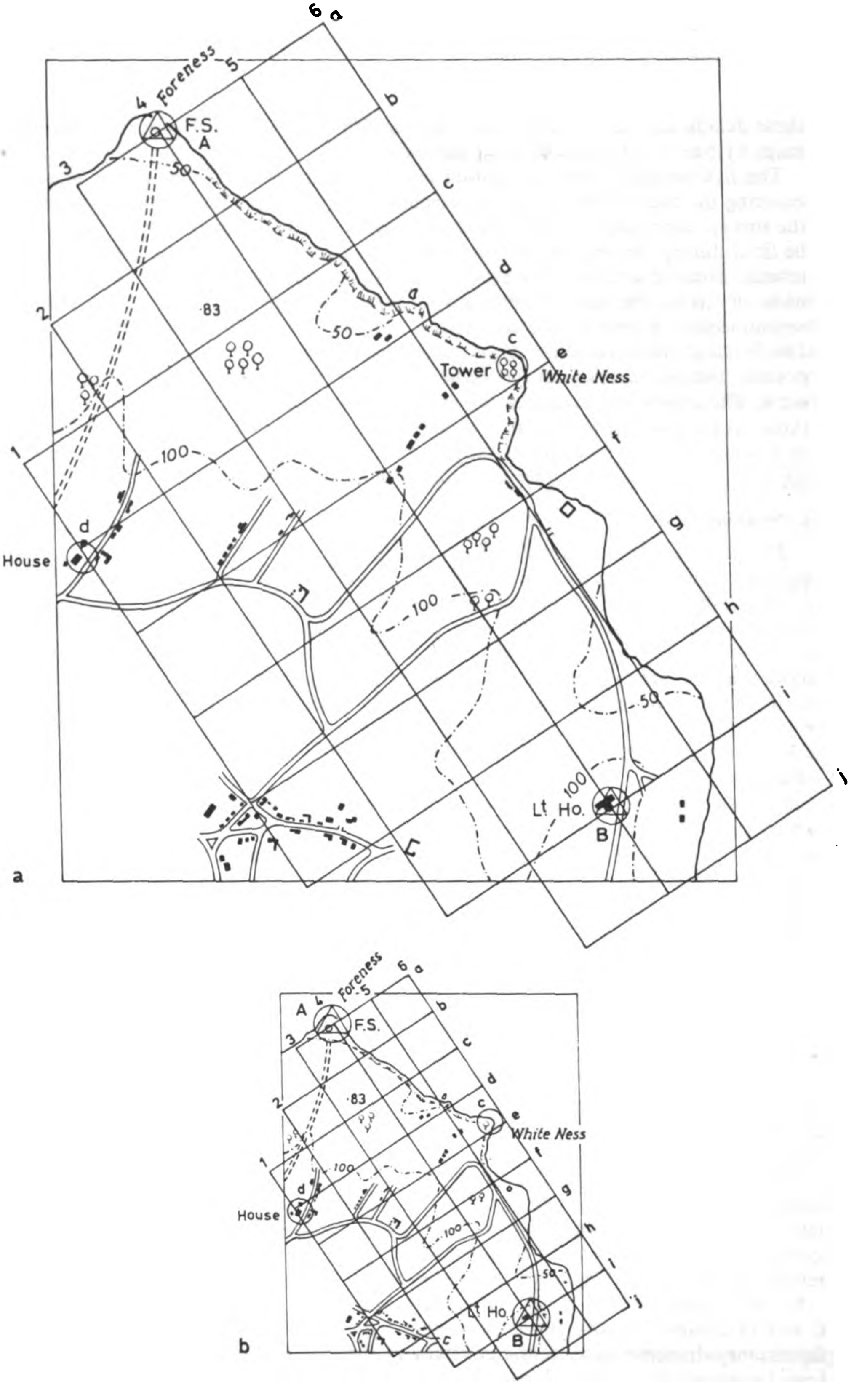
It is essential to make certain that the selected points on the map have been correctly identified when they are fixed on the hydrographic survey. In addition to the base line terminals it is advisable to fix on the hydrographic survey a few other points appearing on the map. The position of these, in their respective squares, should be checked to ensure that there is absolute agreement.

For example, Fig. 5–4(a) is a portion of a map on a scale of 1/21,800 which it is required to square-down to 1/50,000, the scale of the hydrographic survey. The result is shown in Fig. 5–4(b) in which the points A and B, a flagstaff and a lighthouse, are trigonometrical points near the limits of the area of the survey and which can be identified on the map. In addition, the points C and D, two sounding marks, were plotted on the field board and can be identified on the map.

The line AB is therefore used as the base. This is divided up as shown in the figures and a system of corresponding squares is drawn to cover the area. It is convenient to number and letter the lines (or the squares) as indicated to prevent mistakes in transferring the detail. Great care must be taken in the construction of the squares; any error in drawing them will result in inaccuracy when detail is transferred.

In the example shown, when the squares are drawn, it is found that the sounding marks C and D occupy the same positions as they would if transferred from the map. This gives a satisfactory demonstration of the accuracy of the map and a proof that the points A and B have been correctly identified.

The topography, in this example consisting of roads, houses, contours and trees, can be



SQUARING DOWN

FIG 5-4

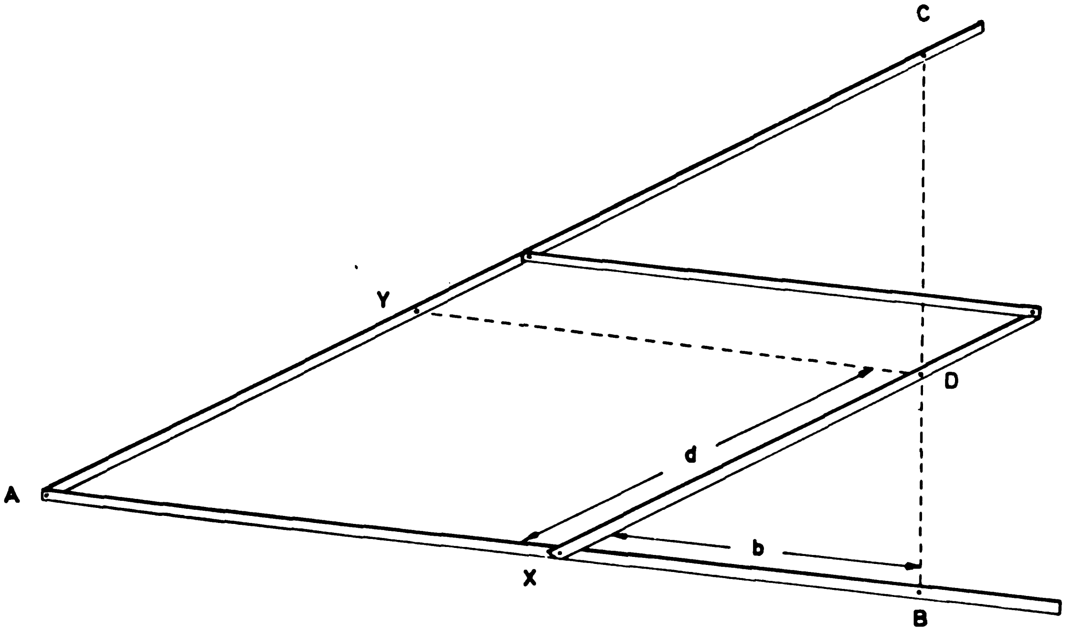
easily transferred to the field board by means of a pair of proportional dividers. The dividers should be adjusted to the ratio of the two scales. The detail is then transferred by measurements with the dividers from the sides and corners of the square in which it lies in the original. The corresponding measurement on the reverse end of the dividers is used to plot the position in the corresponding square on the field board. If proportional dividers are not available, distances can be plotted with a pair of ordinary dividers. All distances transferred from the original must, however, have the appropriate reduction ratio applied to them, either mathematically or graphically, before transfer to the field board.

In making the copy it is necessary to omit many of the less important topographical details which cannot well be shown on the reduced scale. Some features, such as the width of the roads and cliff detail, must be exaggerated.

The process of squaring-up is done in a similar manner to squaring down, but any error in the original is increased. For this reason, the results are not always satisfactory and careful consideration must be given to the question of whether they will fulfil the requirements of accuracy.

b. Transfer of Topography with a Pantograph

Where large areas of topography are to be transferred, this may be done more easily and quickly with a pantograph. This mathematical drawing instrument requires a large area of flat table (or floor) space for its operation. As with squaring up or down and any other method of transferring topographical detail between different scales, points on the original map must be checked against their fixed positions in the survey being undertaken. Also all selected points must be correctly identified before being fixed as described above for squaring down.



(a) DIAGRAM TO ILLUSTRATE THE PRINCIPLE OF THE PANTOGRAPH

FIG 5-5

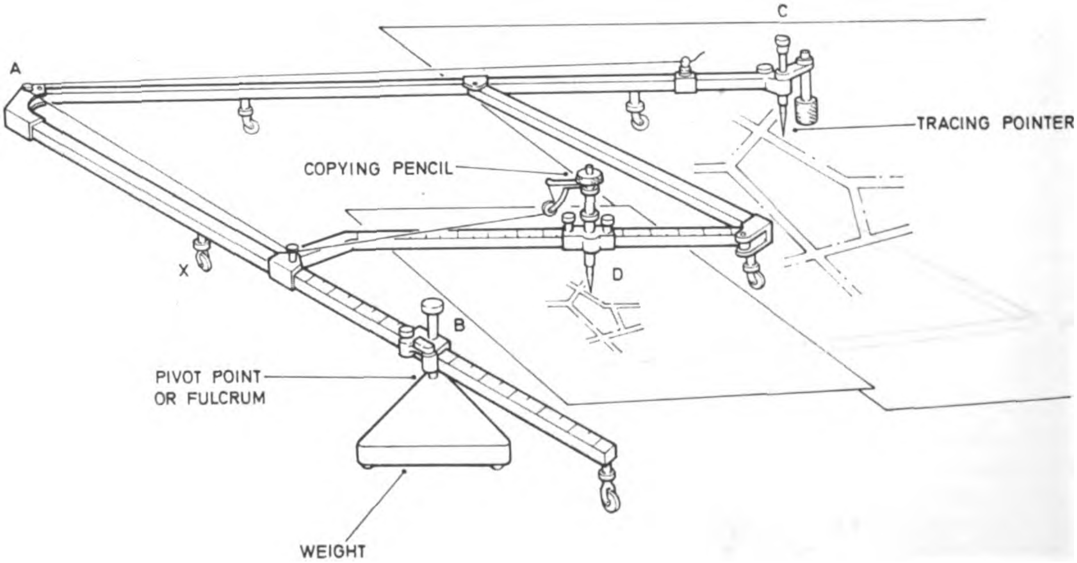
(i) The Pantograph

In principle, the pantograph depends on similar triangles to change the scale of the transferred work. The instrument consists of four levers hinged together to form a parallelogram as shown in Fig. 5–5(a). Two of the levers are twice the length of the others and extend beyond the parallelogram. In the figure the levers are shown as thick, full lines. If the instrument is pivoted at B and point C is moved to follow the outline of the shape, point D will also follow the same shape but reduced in size. Exactly the same applies if the instrument is pivoted at C when point D will follow the movements of point B but in this case the reduction in size will not be as great. In either case the shape copied will be the same way round as the original shape and is known as scaling down by the *erect* method. The instrument can also be used to enlarge by the opposite process – i.e., by changing over the tracing pointer and copying pencil.

If the instrument is pivoted at point D, point B will follow the movements of C at a reduced scale, only in this case the shape produced will be inverted to the original traced out by C. This method is called scaling down by the *reverse* method and is the best method of using the pantograph when the original map to be scaled down is large and a large area of it is to be reduced. In this method, the original and copy sheets can be placed so as not to overlap.

On the instrument, point C is fixed while points D and B are adjustable and will slide up and down their respective arms and clamp in position to obtain the required ratio of reduction. Although the instrument can be used for enlarging, this should never normally be done in practice in reproducing maps and charts as any inaccuracies in the original or in tracing the original are increased in the reproduction. When correctly set, the points C, D, and B lie in a straight line.

In the Stanley Pantograph, as supplied to surveying ships of the Royal Navy, the sides of the jointed parallelogram are equal and considered to be 100 units long; the long arm AC is exactly 200 units long while the other long arm AB is also 200 units long overall but the position of point B is adjustable. The arms D and B are graduated in 100 units measured from point X. The sliders on the arms D and B are fitted with simple verniers to enable them to be set with precision. The pivot rod, tracing pointer or copying pencil can be fitted into sockets on either slider or at the fixed position C. In operation, the instrument is supported by the pivot and by small casters at other points on the instrument (see Fig. 5–5(a) and (b)).



(b) PANTOGRAPH AS SET UP FOR REDUCING BY THE ERECT METHOD

FIG 5-5

(ii) To reduce by the ERECT method in a ratio of MORE than 2:1. (Fig. 5–5(b))

For this, the pivot or fulcrum is fitted in the socket on the slider on arm B, the tracing point at C and the copying pencil at D. The triangles ABC and XBD are similar, when correctly set, so that:

$$\frac{AC}{XD} = \frac{AB}{XB} = R$$

Where R is the ratio, i.e. when reducing from a scale of 1/10,000 to a scale of 1/50,000, R = 5.

If the setting on arm B is b and the setting on arm D is d, then,

$$\frac{AC}{XD} = \frac{200}{d} = R \qquad \therefore d = \frac{200}{R}$$

$$\text{and} \quad \frac{AB}{XB} = \frac{100 + b}{b} = R \quad \therefore b = \frac{100}{(R-1)}$$

(iii) To reduce by the ERECT method in a ratio of LESS than 2:1

If the reduction is less than 2:1 and the above calculation is made, d and b will be found greater than 100 which will be impossible to set. In this case, the pivot is fitted at the fixed point C, the tracing point at B and the copying pencil at D. Here the similar triangles ABC and YCD are considered:

$$\frac{AC}{YC} = \frac{AB}{YD} = R$$

$$\text{So,} \quad \frac{AC}{YC} = \frac{200}{200-d} = R \qquad \therefore d = \frac{200(R-1)}{R}$$

$$\text{and} \quad \frac{AB}{YD} = \frac{100 + b}{100} = R \quad \therefore b = 100(R-1)$$

(iv) To reduce by the REVERSE method (Fig. 5–5(c))

For this, the pivot is fitted at D, the tracing point at C and the copying pencil at B. In this case, the similar triangles YCD and XDB are considered. As these are either side of the pivot point D, the copied result will be inverted, and:

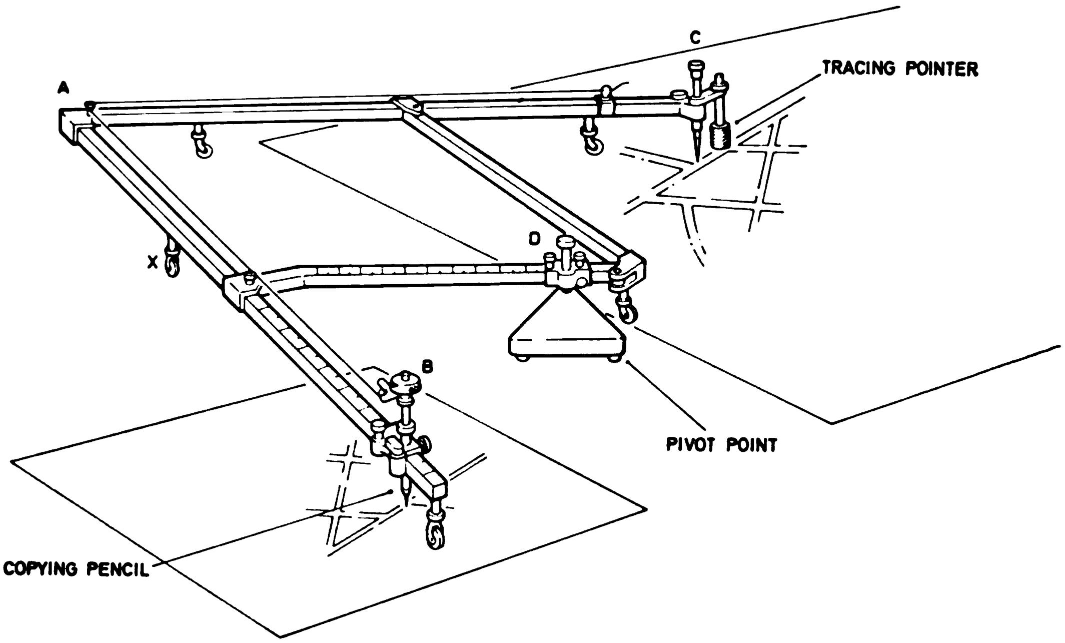
$$\frac{YC}{XD} = \frac{YD}{XB} = R$$

$$\text{and so} \quad \frac{YC}{XD} = \frac{200-d}{d} = R \quad \therefore d = \frac{200}{(R+1)}$$

$$\text{and} \quad \frac{YD}{XB} = \frac{100}{b} = R \qquad \therefore b = \frac{100}{R}$$

(v) Operation of the Pantograph

When using the instrument by either the erect or reverse method, the calculated settings are first set on arms D and B. The fulcrum rod or pivot point, tracing point and copying pencil are then shipped in their appropriate sockets. The instrument is then sited on the table in a position where there is sufficient room for movement. It is important that the table is flat and true as well as of sufficient size. The map to be reduced in size is placed under the tracing point and a sheet of tracing paper or transparent plastic material is placed under the copying pencil. The sheet of tracing paper or plastic material is first "pricked off" from



(c) PANTOGRAPH AS SET UP FOR REDUCING BY THE REVERSE METHOD

FIG 5-5

the plotting sheet of the survey to cover the area concerned and all survey marks should be shown. As with reducing by squaring down, at least two of these should be identifiable on the map from which the reduction is being taken; these marks should be near the extreme limits of the sheet or as far apart as possible and additional identifiable points are desirable as a check on the accuracy with which the map detail is being followed and to guard against backlash in the pantograph.

To set up the map and tracing for reduction, the tracing pointer on the pantograph should be first set over one of the identifiable marks on the map. The tracing should then be placed so that the same mark on it lies under the copying pencil. The tracing should then be pivoted about this point until the line between the two marks on the tracing lies parallel to the line between the same two marks on the map. The alignment should then be checked by placing the tracing point over other marks on the map and seeing that the copying pencil lies exactly over the same marks on the tracing. The copying pencil on the Stanley pantograph can be lifted off the paper by a lever arm operated by a length of string running from a position near the tracing pointer. While reducing by the erect method, it is normally necessary to have to place the map and tracing so that they overlap. When copying by the reverse method it is not usually necessary for them to overlap as shown in Fig. 5–5(c).

c) Transfer of Topography by Photographic Methods

An accurate and effective method of transferring topography with a change of scale is by photography. A photograph is taken of the original map and the result is then projected and reduced so that it corresponds exactly to the scale of the survey to which the topography is being transferred. A print is made of the projected result, preferably on transparent material, which can be fitted over the fixed points on the topography board or tracing and traced off.

The photographic equipment for this type of enlargement or reduction work is large and expensive and is not generally available except in map or chart producing establishments.

12. Topographical Work in the Field

The methods adopted for filling in the topographical detail of a hydrographic survey must be varied to suit the character of the land features, the scale of the survey, the means and time available. The more important hill summits and other conspicuous objects should be fixed and their heights determined by theodolite angles from main and secondary stations or other suitable, fixed stations. When these points have been plotted and heighted, they provide a framework of control in the horizontal and vertical planes and are of great assistance in interpolating other detail of minor importance.

A separate field board should be prepared for topographical work. This board should show all the fixed stations of the survey, main and secondary trigonometrical stations, sounding marks, etc., with any heights already obtained. The coastline should be shown, at least approximately if not already coastlined, as a knowledge of its position and shape is usually a valuable guide to the form of hill features in its vicinity.

The normal procedure in topographical work is for an observer to examine as much as possible of the required area from a number of points on the ground. Each point occupied is accurately fixed, if not already done so, by resection. These points must be selected so that a good view of the surrounding country can be obtained from them in order to observe the fix and other rays to all prominent and easily recognisable features that can be seen. Elevations and depressions should also be obtained to these features to height them. In this way, features are fixed by obtaining three or more good intersections into them and heights can be determined from the average of calculated results of the observations of elevation or depression. When all hill summits and other detail have been fixed and heighted, the contour or form lines can be sketched in from a knowledge of the configuration of the terrain.

To this end it is usually best to work along the highest part of each ridge of hills and on the spurs which extend from them. Numerous eminences or summits should be occupied and from them rays should be observed to other summits and to any and all recognisable features that can be seen, including those in the bottoms of valleys and on the sides of hills. These features may include such objects as conspicuous trees, houses, outcrops of rock, flagstaffs, chimneys, pylons, sharp bend in a river, waterfall, road junction, etc. Where possible, elevations or depressions should be observed to them or to the ground on which they stand so that they can be heighted to facilitate the sketching in of contours or form lines with sufficient accuracy for the purposes of a chart.

Horizontal angles may be observed by sextant, level, theodolite or plane table alidade, whilst on very small scales a compass will often do well enough. However, if objects vary considerably in elevation or depression, only a theodolite or plane table alidade are satisfactory. In addition, only a theodolite or plane table having a telescopic alidade with a vertical arc are suitable for observations of elevation or depression ashore for heighting. Heights can also be obtained with an aneroid barometer (see Volume 1, Chapter 9).

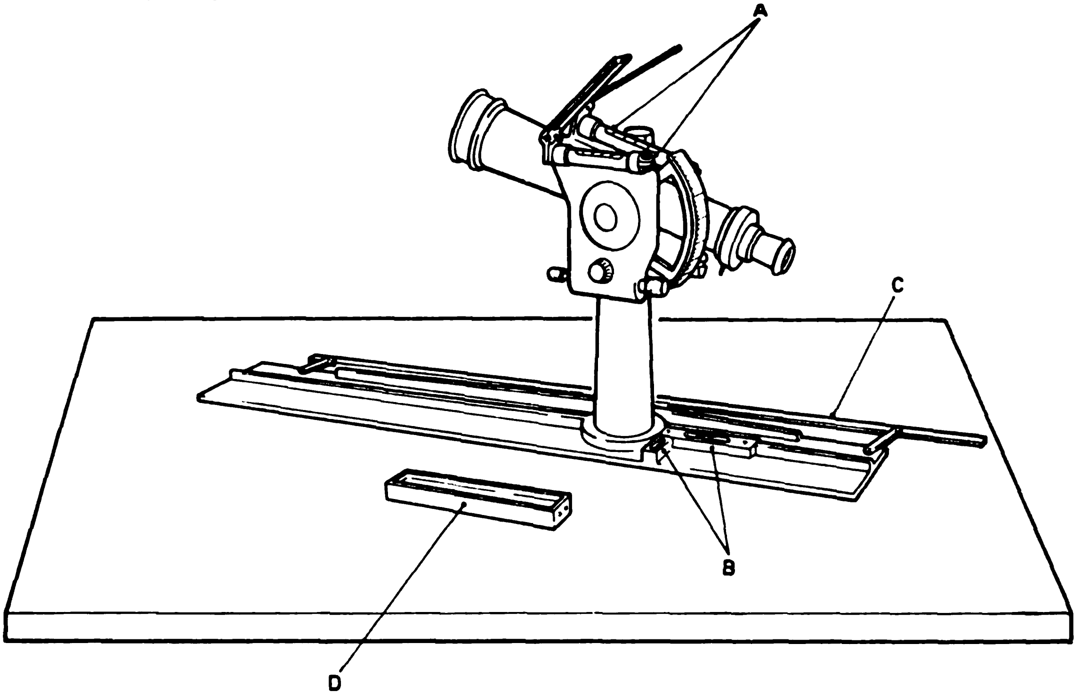
No firm rules can be laid down as to the best type of instrument to use in topography. In wooded country it will be impossible to occupy many points on land that command a good view. Under these circumstances the topography can be built up from the analysis of a series of sketches of views, with horizontal and vertical angles observed, taken from ship or boat stations offshore and any land stations from which a view can be obtained. This method has the advantage that the field work is quickly carried out and that features of interest to the mariner are not omitted. It involves, however, a considerable amount of patient work in the drawing office.

For mapping towns, villages and other involved topographical features on large scales, it is usually necessary to resort to traverse methods. For this a theodolite or a level with a horizontal circle should be employed and the method used similar to that described for coastlining in Section 3. Until the general use of air photography for obtaining topographical detail, the topographical surveyor did the greater part of his work with a plane table and this is undoubtedly the best instrument to use in most cases. In the next section, the plane table and the method in which it is used is described. For a fuller description, Close's *Textbook of Topographical Surveying* should be consulted. The method of obtaining topography from the analysis of views, mentioned above and often used in hydrographic surveys, is described in Section **14** below.

13. Topography by Plane Table

a. General description of the plane table and alidade

A plane table consists of a board, mounted on tripod legs in such a way that it can be adjusted to the horizontal and turned in azimuth, and an alidade for observing the rays. The positions of the fixed marks of the survey, magnetic meridians and scales of miles, cables and feet are transferred to the plane table itself which is mounted with drawing paper and used as a topographical field board.



PLANE TABLE AND TELESCOPIC ALIDADE

FIG 5-6

The various parts can be seen in Fig. 5–6 and are:

(i) The board already described.

(ii) The tripod legs. Levelling screws are fitted on the tripod head to level the board. A clamp and slow-motion screw are provided for orientating the board.

(iii) The alidade. A telescopic alidade fitted with a vertical arc, reading to minutes, is illustrated. The telescope is fitted with stadia wires for tachymetric measurements and is fitted with an upper level, like a theodolite, to provide a horizontal datum for observations of elevation and depression. The alidade is quite separate from the board.

(iv) The parallel bar. This forms part of the base of the alidade and works on the principle of the sliding type of parallel ruler. Its edge is parallel to the line of collimation of the telescope.

(v) Spirit levels for obtaining the horizontality of the board. These are situated on the base of the alidade at right angles to one another or in some instruments, a single, circular level is used.

(vi) The trough compass. This is used for aligning the magnetic meridian drawn on the board with the actual magnetic meridian when required.

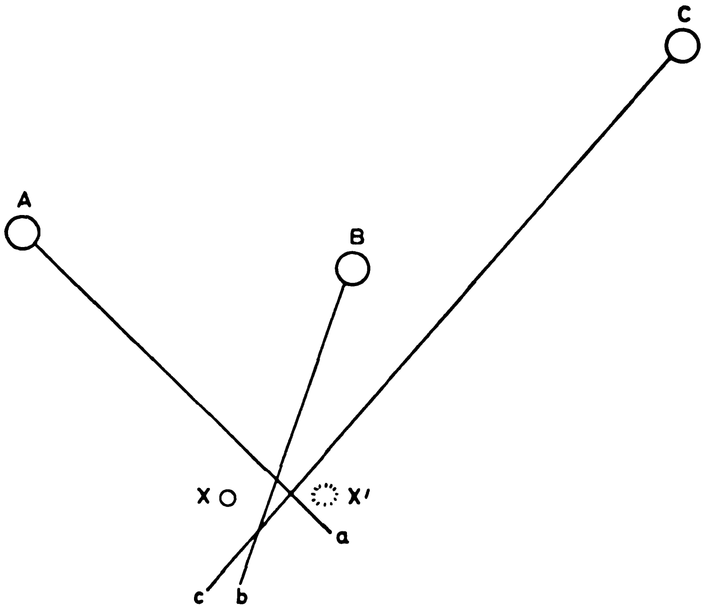
Plane tables, simpler than the type illustrated, are sometimes used which are supplied with open-sighted alidades. In an instrument of this type, the board is generally secured to the tripod head by a ball-and-socket arrangement which permits adjustment in tilt and azimuth. A separate spirit level placed on the board enables it to be adjusted into the horizontal plane while an ordinary compass can be used to orientate it along the magnetic meridian. Such a plane table, fitted with an open-sighted alidade, is much lighter than the one illustrated and serves for many purposes just as well. The main disadvantage is that it may be difficult to intersect a distant object accurately with the open sight. Also, no ranges can be obtained by tachymetry. If a clinometer is provided, it can be used for obtaining vertical angles but these cannot be observed with much accuracy when using an open sight.

b. Setting up and using the plane table

The procedure is very simple if the instrument is to be set up at a previously fixed point. The board is first levelled and the alidade ruling edge on the parallel bar is aligned on the prickholes on the board marking the observer's position and a distant visible mark. As the line of sight of the alidade is parallel to this ruling edge, the board can be quickly and accurately orientated by turning it in azimuth until the distant station is intersected with the alidade sights. The board should then be tightly clamped in position. To prevent any possible mistake in identification, the alidade should then be directed at another fixed mark. If the parallel bar is then aligned on the prickhole indicating the position of the second mark on the board and the ruling edge is found to pass through the prickhole marking the observer's position, then the board can be considered to be correctly set up. All visible and recognisable features should then be observed to and rays drawn in on the board at their approximate positions. This should be done with a chisel-edged pencil run along the parallel bar after it has been aligned on the prickhole marking the observer's position. The rays should be labelled to prevent later confusion. Elevations and depressions should also be obtained, if the height is required, and noted in a field book.

When the instrument is set up at an unknown position, it is necessary for the observer to fix his position on the board by graphic resection. The marks must be selected to give a good fix. Having set the board up it is levelled and approximately orientated with the aid of the trough compass. This is done by placing the compass trough along the magnetic meridian drawn on the board and turning the board until the compass needle is central. The board is then clamped and the three marks selected for the fix are intersected with the alidade. Suppose the three stations A, B and C shown in Fig. 5–7 have been selected to obtain the fix. Station A is first intersected with the alidade sight, the ruling edge of the parallel bar is then aligned on the prickhole A on the board and the ray Aa drawn in the vicinity of the observer's position. Similarly, the stations B and C are intersected and the rays Bg and Cc drawn. The result will probably be a small triangle of error, as shown in the figure.

If the observer is situated *outside* the triangle formed by the three distant stations, his position is *outside* the triangle of error and *vice versa*. The actual position of the observer must be a point where the three rays would meet if they were all turned through ***equal angles*** in the *same* direction, clockwise or anti-clockwise. The distant station should be regarded as the centre of the clock in determining the direction of movement. This means that the distance



"SWINGING RAYS" OBTAINED BY PLANE TABLE OBSERVATION

FIG 5-7

of the observer's true position from each ray (or "offset") is proportional to the observer's distance from each station. In the case illustrated in Fig. 5–7, the true position can be interpolated fairly accurately by eye as the point x, and this is the only position which fulfils the above requirements.

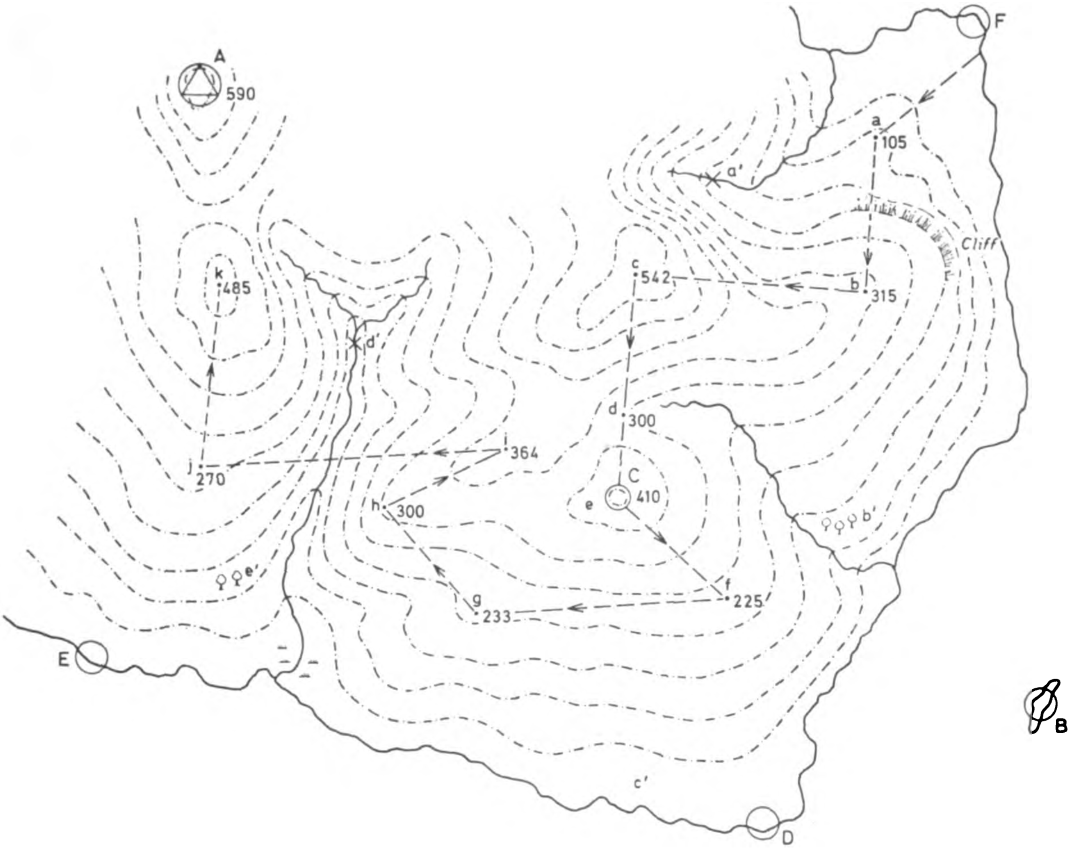
At first sight, it might be thought that the observer's position could be in the space marked x′, since all the rays might be swung anti-clockwise in that direction. A moment's inspection, however, will show that no position in that space can be at a distance from the rays proportional to that of the observer from the stations.

Having obtained a fairly accurate position for x, the parallel bar is then aligned with this position and the prickhole marking the most distant station, in this case C. The board is then turned in azimuth until C is intersected with the alidade sights; this movement should only be a small one. The table is then clamped in position, the first rays are erased from the board and the ray Cx drawn. A and B are then successively intersected, the alidade edge aligned on their respective prickholes and the rays from A and B drawn. If the previous interpolation has been good, the three rays will now meet at x. If not, there will be another smaller triangle of error and the final interpolation should be easily and quickly obtained by eye with all the required accuracy. The board will then require a small further alteration in azimuth to be orientated correctly. As a final check, a fourth station should be intersected with the alidade and when the parallel bar is aligned with its prickhole on the board, the ruling edge should pass through the accepted position.

When only two distant stations are visible, it is necessary to rely solely on the compass for orientation and fixing. This is not so satisfactory but is acceptable when the rays are short as represented on the board and the cut is good.

The chief advantages of using a plane table in preference to a theodolite for topographical work is that it saves clerical work and the plotting can be carried out directly as the work is progressed. Rays are drawn as soon as they are observed and there is no need to read out and write down a large number of horizontal angles which have to be plotted later with a different instrument. Only vertical angles are recorded. When there are numerous rays from a station they must be carefully annotated to avoid confusion.

Suppose it is required to sketch in the topographical detail shown in Fig. 5–8 with the aid of a plane table. If vertical angles cannot be measured, an aneroid barometer will be required for heighting.



TYPICAL PLANE TABLE TRAVERSE

FIG 5–8

Landing near F, the aneroid barometer should be checked at sea level. The observer then proceeds to a point *a*. He sets up the table, resects himself from A, C and B and observes a check ray to F. He heights himself with the aneroid or by obtaining an angle of depression to the water line at the islet B. Rays are then observed to all recognisable and easily identifiable features in sight, such as to a small waterfall *a'*, the limits of the cliff face to the south, summits of unfixed hills, etc. If possible, angles of elevation and depression are also obtained for heighting. The rough form lines in the immediate vicinity should then be sketched in to indicate the shape of the terrain. These can be amended later when heights have been determined and features finally fixed.

The observer then goes to *b* on the shoulder of the hill and carries out the same procedure. Rays to features already intersected at *a* will indicate their position, but a third ray should also be obtained at a later station if possible as a check and the rays must make a satisfactory cut. Similarly the observer occupies other points such as *c*, *d*, *e*, etc., following the track indicated by the pecked line. At position *e*, he occupies the fixed point C so here no resection will be necessary. In addition, if the height of the position has already been determined, it will be possible to check the aneroid or the vertical angle observations. In this way rays to intermediate points such as the houses at *c'*, the junction of two streams marked by a conspicuous rock *d'*, the tree clumps *b'* and *e'* are obtained from various positions and the features fixed. Many of these may not be of much interest to the mariner but they are of great assistance to the observer in drawing in his contours correctly.

If an aneroid barometer is used, it should be read on reaching sea level again and the procedure described in Volume 1, Chapter 9, should be carried out to obtain heights.

14. Topography from Sketches

In a hydrographic survey, where the terrain can be viewed from a ship or boat from several positions out at sea as well as from stations ashore, this method is very convenient. It is particularly convenient where the country is wooded and it would be hardly feasible to do much topographical work by plane table or by traverse methods.

In this method, the outline view from each station of all the hills (and other easily recognisable features) is drawn on squared paper, approximately to scale. The vertical and horizontal angles are observed to all prominent features and noted on the sketch. On all sketches the scale used for the vertical angles should normally be somewhat greater than that for the horizontal angles, unless the country is very mountainous. A vertical scale 1½ to 2 times the horizontal scale is normally convenient. Too much time need not be spent in attempting to make a very perfect sketch; certain features may often be a little exaggerated in height or breadth if it will enable their character to be more easily deduced from the picture. It is, however, important that all features are correctly placed on the sketch in relation to neighbouring objects, either right or left, above or below, as they are seen from the observer's view point. The sketches are then collected together and the features are plotted on a topographical board by plotting the rays to them from the positions of the various view points. These features can then be heighted from the vertical angles and form lines sketched in to fit the spot heights according to the detail shown in the various sketches.

To carry out this work, a field board must first be prepared, as with other methods of topographical work, with the positions of all fixed stations pricked off and marked. The coastline and any topographical detail already obtained should also be added. The board, together with drawing instruments, sketch book of squared paper, sextant, station pointers, *Tables for Facilitating the Calculation of Heights* and a predicted tidal curve for the day are required for carrying out the observations and plotting the detail. The ship or boat is first anchored a mile or so offshore, or rather more if the land is high, near one limit of the survey, and fixed in the ordinary way by sextant angles. The topography is then sketched in as shown in Fig. 5-9, and the horizontal and vertical angles observed to all the more prominent features. When this is completed, the ship or boat proceeds a little way along the coast, anchoring in a second position. It is very important that the observer should watch the land features very carefully as the vessel proceeds from position to position. In this way the relative positions of all summits and other features are appreciated as the view point changes and they are correctly labelled to correspond with the first sketch. The appearance of the land changes very rapidly as the view point is altered, especially if some time has elapsed between the occupation of stations.

At the second position, a fix is obtained and the same procedure followed. Further stations are occupied across the survey area and sketches obtained. Sketches are also obtained from fixed positions ashore, the angles being observed with a theodolite. The time at which the various positions are occupied must be noted so that calculated heights may be subsequently corrected for height of tide. Approximate heights can be obtained in the field, if desired for checking summits, with the aid of the predicted tidal curve. The number of views required will depend upon circumstances, especially the size of the area concerned, but five will usually supply sufficient information to cover a fairly large area.

It is desirable, especially to the more important summits, to obtain three or more horizontal angles to all features fixed. This ensures against errors of observation, identification, and plotting. The series of spot heights provide a basis for drawing in the contours.

In the example given, the results of analysing the sketches from A and B and ashore from main trigonometrical stations at A and J, are shown in Fig. 5–10. Actual tide readings should be consulted to obtain more precise hydrographic heights. When the country is wooded, vertical angles are taken to the tops of trees on the summits and the height qualified by the letter "t".

After the topography has been plotted from an analysis of the sketches, it will often be found advantageous to proceed slowly along the coast checking all detail.

Panoramic photographs offer an alternative to sketching, but for the type of work considered here, they are hardly likely to be of great use. The advantages of a sketch over a photograph are that there are no restrictions as to the scale of the view and it is possible to exaggerate detail as necessary. Also, unless the light is favourable, hills in the foreground may often merge against hills in the background in a photograph, but may be brought out in a sketch after careful examination of detail with a pair of binoculars.

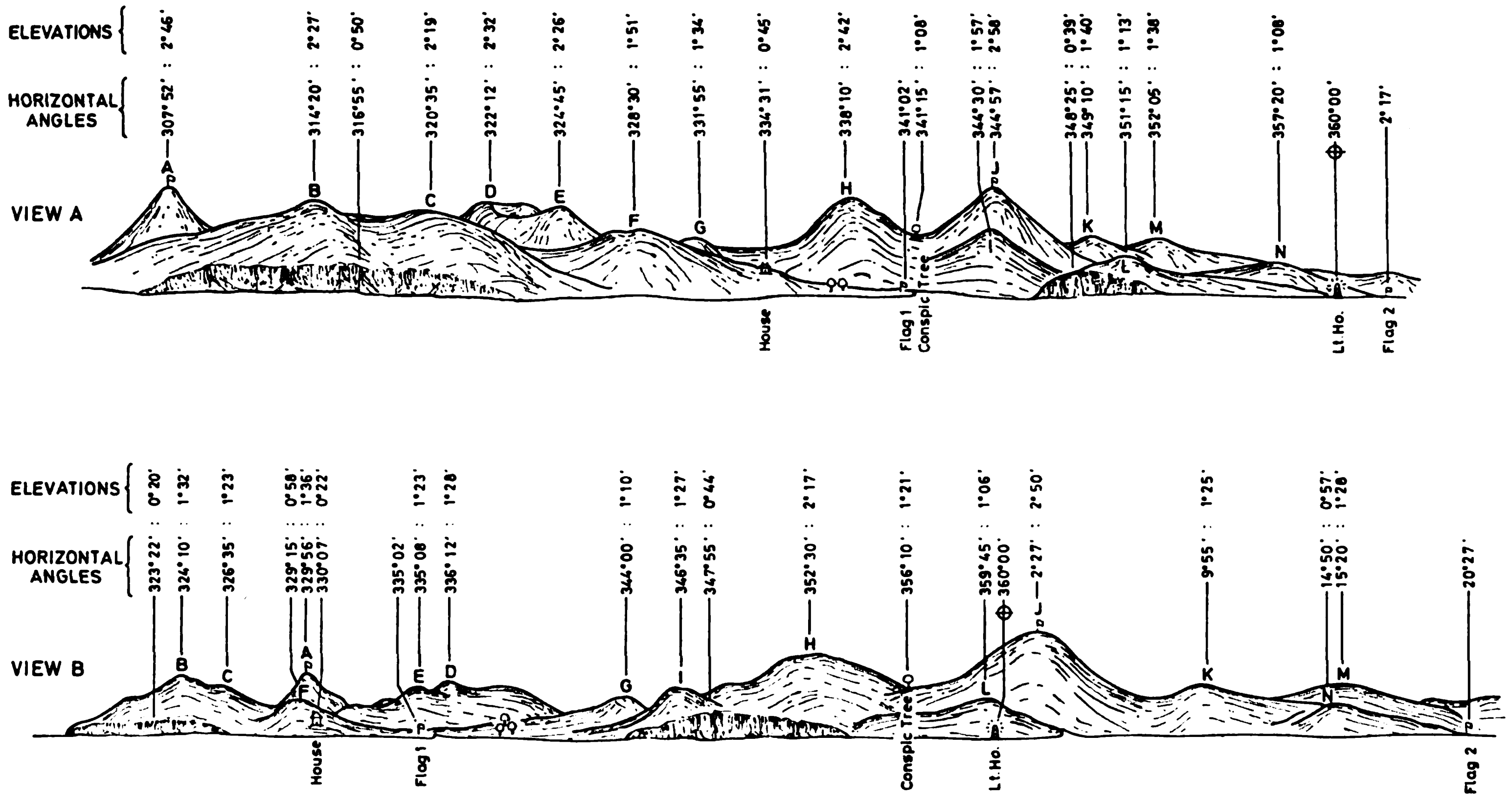
15. Contouring and Form Lines

Contours are generally recognised as the most suitable means of depicting the shape of the land on maps and charts although other methods are sometimes used. Hachures were often used on Admiralty charts in the past. Graded colour washes to supplement the contours are hardly practicable on published charts but may be feasible on fair survey sheets. Shading on south-east slopes of the hills is a useful adjunct and helps to make the shape of the terrain stand out.

The vertical interval between contours must be varied to suit the character of the land and the scale of the survey. In low-lying country a hill 15 m high is an important feature and it may be desirable to have contours spaced at only 5 m vertical intervals. In mountainous country, however, contours at 50 m or 100 m intervals may be all that are necessary to show the shape of the ground. On small scales it is obvious that very close spacing is impracticable.

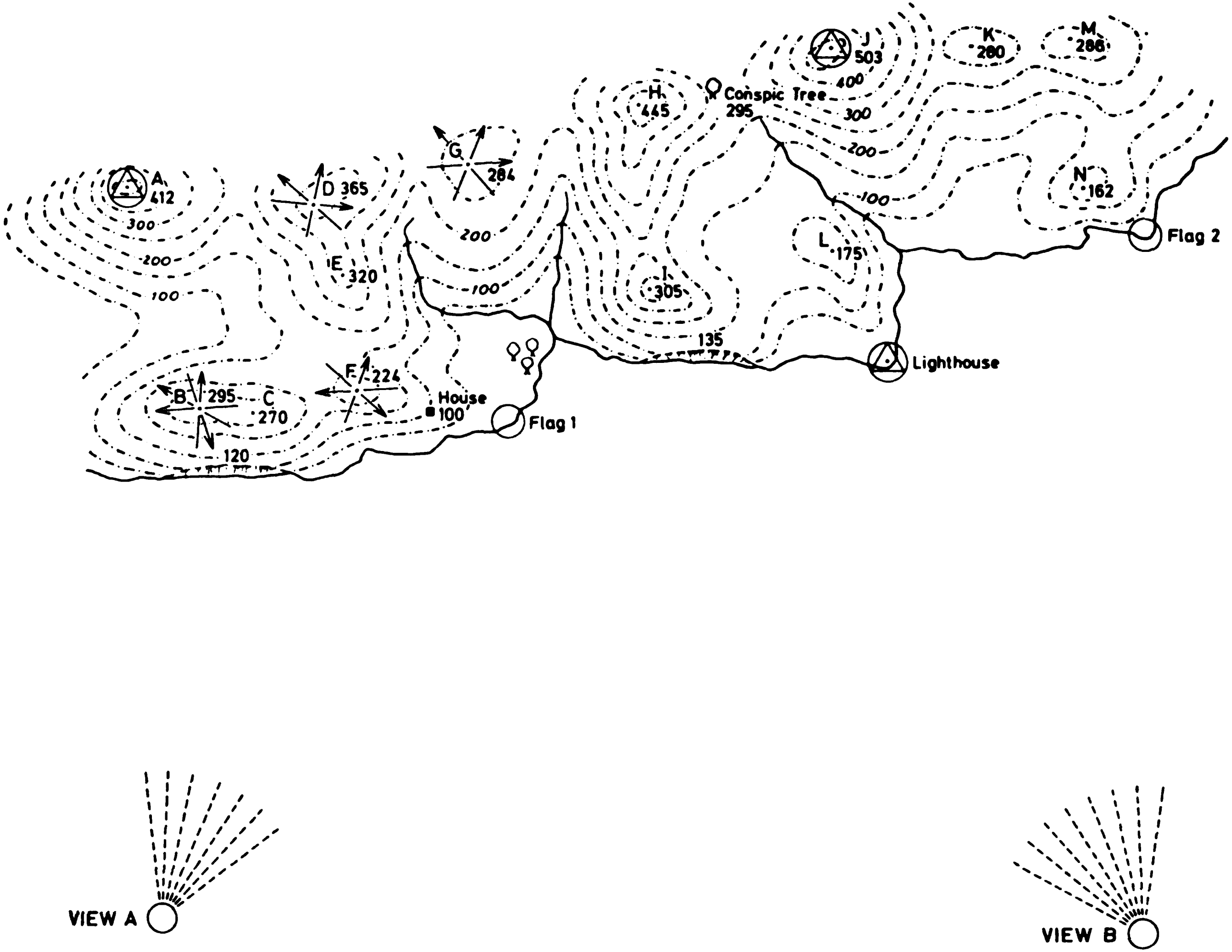
The normal way of obtaining contour lines for land topography in hydrographic surveys is to fit them between a series of spot heights assisted by sketches or air photographs to obtain their shape. This method has been described in previous sections and it is clear that no very great accuracy is obtainable unless the number of plane table or ship stations is multiplied almost indefinitely. For hydrographic surveys it is usually best not to attempt contouring in the strict sense of the word unless they can be taken from maps. Instead, the shape of the hill features can be just as well shown with form lines which may be regarded as generalised contours of unspecified height. The only essential requirements for form lines is that they should indicate different degrees of slope reasonably well by being close together on steep slopes and further apart on gentle ones. They should also show the shape and limits of each feature with reasonable accuracy.

More precise contouring can be done with the aid of air photographs and a large stereoscope fitted with a device called a Parallax Bar. This is the method now most commonly used in



TYPICAL SKETCHES OF VIEWS USED TO OBTAIN TOPOGRAPHICAL DETAIL

FIG 5-9



TOPOGRAPHY OBTAINED FROM SKETCHES SHOWN IN FIG 5-9

FIG 5-10

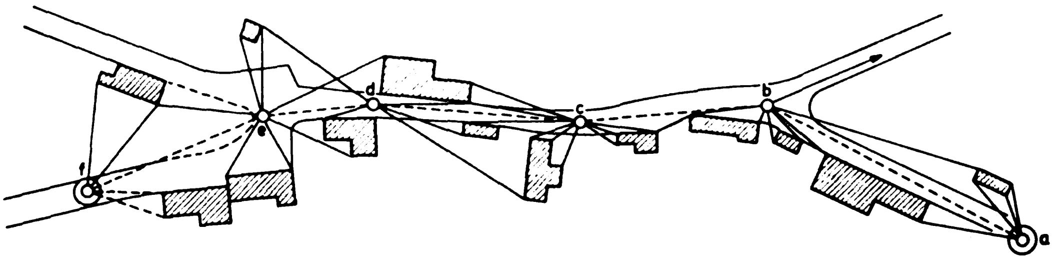
most detailed land surveys. For this method spot heights are still required to prove control for heighting measurements with the Parallax Bar.

There is a much more precise method of heighting and delineating contour lines in the field than any of the methods described above. The method is necessarily slow and laborious and its use is not normally justified except in very large scale surveys where very precise contour lines are required. The procedure is as follows. Starting at some known height – usually sea level in the case of the hydrographic surveyor – the observer runs a line of levels (see Volume 1, Chapter 9) until he arrives at some selected contour value, e.g. the 50 m level. Setting up the level at this point, a fix is obtained and the height of the telescope above the ground is measured. An assistant with a levelling staff is then directed to walk with it as nearly as possible along the contour, stopping and holding up the staff whenever a marked change in the direction of the contour occurs. At each stopping place the levelling staff must be moved up or down the hill until the telescope crosswire intersects the mark on the staff corresponding to the height of the level above the ground. A horizontal angle and a tachymeter distance are then observed to that point which corresponds to an "intermediate point" in coastlining by traverse described in Section 3 of this chapter.

When the assistant has covered a distance approaching the maximum distance that can be measured by tachymetry with reasonable accuracy – generally about 300 metres, depending on the type of level and the conditions, he stops once again. The horizontal angle and tachymetric distance are measured to this point which becomes a "turning point" in the traverse along the contour line. The level is then brought forward to this point and set up and the process repeated. Traverses can be run along other contour levels in a similar manner and, to save time, they should be widely spaced, intermediate contours being drawn in by eye.

16. Mapping of Towns and Villages

On small scales any attempt to make an accurate plan of a town or village can hardly be justified. It will be sufficient to show the more conspicuous buildings, fixed by resection or intersection, and to indicate the approximate limits of the built-up area. On large scales, however, it is necessary to show at least the main streets and blocks of houses. These are best delineated by means of a traverse through the streets which can be carried out in the same way as a coastline traverse described in Section 3, using a level or theodolite. Alternatively, a plane table, preferably with an open-sighted alidade, can be used in conjunction with a small rangefinder, pocket compass and tape measure.



TOWN TOPOGRAPHY OBTAINED FROM A TRAVERSE

FIG 5-11

Suppose it is required to make a plan of the village shown in Fig. 5-11 on a large scale Setting up the plane table at *a*, the observer fixes his position by resection and measures the lengths and bearings of the rays to corners of the nearest houses. Similarly at the turning points of the traverse run through the village, *b*, *c*, *d*, etc., other rays and distances are observed. At *f* the surveyor finds he can again see to fix his position and satisfies himself that accurate closure of the traverse has been made. When possible, two or more rays from different stations should be obtained to each building whilst its exact shape and orientation can be determined with compass and tape measure. Owing to the large amount of detail this form of topographical work is very slow, but, fortunately for the hydrographic surveyor, accurate town plans are generally available. These usually only require checking and occasionally some minor corrections and additions.

17. Topography from Ship Stations

A method similar to that described in Section 14 may be employed from the ship underway if it is only intended to chart the more important and conspicuous features of the topography. As many obervers as possible are required, together with a photographer and an assistant to plot the results as the work progresses, leaving the surveyor free to direct operations and con the ship.

The ship stops or anchors and a fix is obtained. Simultaneously, shots into summits, shoulders, escarpments and other topographical features are taken by horizontal sextant angles; photographs of the coast are taken and the ship's head is noted. All the observers must be as close together as possible and also as close as may be to the fixing point, be it the position of other anglers, or the Hi-fix aerial; or allowance must be made in plotting for the separation.

The ship then proceeds towards the next stopping point, chosen to give a reasonable cut at the closest features, whilst the observations are recorded and plotted and the observers given instructions for the next ship station. The procedure is repeated until a feature has at least three shots into it, or, for large features, has been adequately defined by tangents, whereupon observations are commenced to other features farther up the coast and continued until adequate representation has been achieved.

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Metre
1
2
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Table for Converting Metres to Feet and Fathoms

Metres	Feet	Fms.	Metres	Feet	Fms.	Metres	Feet	Fms.
1	3·281	0·547	51	167·323	27·887	200	656·17	109·36
2	6·562	1·094	52	170·604	28·434	300	984·25	164·04
3	9·843	1·640	53	173·885	28·981	400	1312·34	218·72
4	13·123	2·187	54	177·165	29·528	500	1640·42	273·40
5	16·404	2·734	55	180·446	30·074			
6	19·685	3·281	56	183·727	30·621	600	1968·50	328·08
7	22·966	3·828	57	187·008	31·168	700	2296·59	382·76
8	26·247	4·374	58	190·289	31·715	800	2624·67	437·45
9	29·528	4·921	59	193·570	32·262	900	2952·76	492·13
10	32·808	5·468	60	196·850	32·808			
11	36·089	6·015	61	200·311	33·355	1000	3280·84	546·81
12	39·370	6·562	62	203·412	33·902	2000	6561·68	1093·61
13	42·651	7·108	63	206·693	34·449	3000	9842·52	1640·42
14	45·932	7·655	64	209·974	34·996	4000	13123·36	2187·23
15	49·213	8·202	65	213·255	35·542	5000	16404·20	2734·03
16	52·493	8·749	66	216·535	36·089	6000	19685·04	3280·84
17	55·774	9·296	67	219·816	36·636	7000	22965·88	3827·65
18	59·055	9·843	68	223·097	37·183	8000	26246·72	4374·45
19	62·336	10·389	69	226·378	37·730	9000	29527·56	4921·26
20	65·617	10·936	70	229·659	38·276	10000	32808·40	5468·07
21	68·898	11·483	71	232·940	38·823			
22	72·178	12·030	72	236·220	39·370			
23	75·459	12·577	73	239·501	39·917			
24	78·740	13·123	74	242·782	40·464			
25	82·021	13·670	75	246·063	41·010			
26	85·302	14·217	76	249·344	41·557			
27	88·583	14·764	77	252·625	42·104			
28	91·864	15·311	78	255·906	42·651			
29	95·144	15·857	79	259·186	43·198			
30	98·425	16·404	80	262·467	43·745			
31	101·706	16·951	81	265·748	44·291			
32	104·987	17·498	82	269·029	44·838			
33	108·268	18·045	83	272·310	45·385			
34	111·549	18·591	84	275·591	45·932			
35	114·829	19·138	85	278·871	46·479			
36	118·110	19·685	86	282·152	47·025			
37	121·391	20·232	87	285·433	47·572			
38	124·672	20·779	88	288·714	48·119			
39	127·953	21·325	89	291·995	48·666			
40	131·234	21·872	90	295·276	49·213			
41	134·514	22·419	91	298·556	49·759			
42	137·795	22·966	92	301·837	50·306			
43	141·076	23·513	93	305·118	50·853			
44	144·357	24·059	94	308·399	51·400			
45	147·638	24·606	95	311·680	51·947			
46	150·919	25·153	96	314·961	52·493			
47	154·199	25·700	97	318·241	53·040			
48	157·480	26·247	98	321·522	53·587			
49	160·761	26·794	99	324·803	54·134			
50	164·042	27·340	100	328·084	54·681			

Metres	Inches
0·10	3·937
0·20	7·874
0·30	11·811
0·40	15·748
0·50	19·685
0·60	23·622
0·70	27·559
0·80	31·496
0·90	35·433
1·00	39·370

Factors: 1 metre = 3·280839895 feet or 39·370078740 inches
= 0·546806649 fathoms

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